fundamentals of CARTOGRAPHY

R. P. MISRA

PRASARANGA, UNIVERSITY OF MYSORE

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Figure 1 : Air Photograph of Palni town.

FUNDAMENTALS
of
CARTOGRAPHY

By

Dr. R. P. MISRA
Professor of Geography
University of Mysore

Assisted By

Dr. A. RAMESH
Lecturer in Geography
University of Madras

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TO

MY PARENTS,

WIFE, AND CHILDREN

FOREWORD

Cartography is a science which tries to represent the interrelations, correlations and combinations underlying the physical and cultural elements of the earth in the language of visual symbols. In its essentials, it is a science and art of making maps. With increasing complexities in the location and distribution of the earth features, the cartographic processes are also becoming more complex. The cartographer of today not only has to prepare maps of the visible surface of the earth but also of the intangible features which can be seen only statistically. Over and above this, he has to prepare maps of the outer space, ocean floors, and other planetary bodies.

In our country cartography has not received adequate attention. It can play an important role in the formulation and implementation of economic plans. In order to utilise our resources fully the spatial dimensions of the national plans have to be mapped out fully. The universities can play an important role to develop these studies by including cartographic programmes in our colleges and universities.

I am glad that Dr. R. P. Misra has come forward with a book on the fundamentals of cartography. The book is comprehensive in scope and deep in treatment. I hope that this book will dispel many of the wrong notions about cartography and pave the way for a better understanding of the science of making maps.

This book fills a vaccum in the list of Indian books available for the students of geography and cartography. I hope that the students of geography and cartography and others who are interested in maps and diagrams will be greatly benefitted by this book.

MYSORE–5
September 24, 1969

K. L. SHRIMALI
Vice-Chancellor

PREFACE

The origin of this book lies in my experiences as, a student, research worker, and teacher over the past ten years. The desire to write it was reinforced when I attended the USNSF summer institutes in cartography held at the Department of Geography, University of Washington, Seattle, USA in 1964 and 1966.

In India cartography happens to be a neglected science. It is often considered to be synonimous with practical geography and drafting of maps. Many a times it is considered to be a branch of mathematical geography. Although it is true that several aspects of practical geography and mathematical geography form parts of cartography, cartography is something more than practical geography or mathematical geography.

In its essentials modern cartography is a science and art of making maps. It is also a science of human communication. It is a function of cartography to provide a true picture of the earth through the medium of maps. Since nothing can represent the earth better than the earth itself, a perfect map is an ideal which can never be achieved. The aim and purpose of cartography is to reach as close to this ideal as possible. To do so, it uses the principles of geodesy, mathematics, geography, human communication, optics, and art in some form or the other. The principles of all these disciplines are encoded into symbols which, when put together, give a meaningful detail of the relevant earth features.

Cartographic process is a complicated process. It involves planning, collection, interpretation and symbolization of data ; map design and construction ; map reproduction ; and map use and evaluation. To define cartography as only an art of drawing maps or as a branch of mathematical geography, is, therefore, not correct.

This book aims at treating cartography in its true perspectives. To keep the presentation systematic and in logical sequence, it has been

divided into 24 chapters. Chapters 1 to 7 deal with such background details as the types and uses of maps, nature and scope of cartography, history of cartography, earth as a cartographic problem, scales, directions, and coordinates. Chapter 8 discusses various types of map projections and their functions. Geodetic and plane surveying is discussed in chapter 9 and aero-surveying in chapter 10. The progress of topographic mapping and the principles of interpretation of topographical and geological maps are given in chapters 11 and 12. Collection and interpretation of statistical data and the principles of map compilation are explained in chapters 13 and 14. Chapters 15, 16 and 17 deal with the design and mechanical aspects of map construction whereas chapters 18, 19, 20, 21 and 22 discuss the methods, techniques and problems of making various types of maps. Map reproduction processes are explained in chapter 23. And finally the problems of cataloguing, storing and marketing of maps are discussed in chapter 24.

Although every effort has been made to keep the presentation in the same order in which a cartography course should be organised and also in which cartographic processes work, these processes are so closely linked with each other that it has not been possible to maintain an order which will be satisfactory from all points of view. To get around this problem, steps discussed later have been brought forward in an introductory way wherever they have bearings upon the earlier steps. This procedure has not only made the understanding of the cartographic processes easier but also has clearly demonstrated the interrelationships underlying various phases of cartographic portrayal.

A book of this nature has its own limitations. As it aims at presenting the whole field of cartography in a logical sequence, the various sub-fields of the subject have not been given as detailed a treatment as one may expect. Reader expert may, therefore, feel that more space ought to have been given to his particular speciality. The author will, however, plead that a detailed treatment of each aspect of the subject would have made the book unwieldy and perhaps less suited to the purpose in view. It should not be necessary to express the hope that the reader specialist will supplement this with other specialised publications which treat certain phases of cartography in greater detail.

Although it is designed primarily as a text book for the students of geography and cartography at the graduate and postgraduate levels, its utility should not be limited to this small but expanding circle. It would be equally useful to the students of geography and cartography

at the lower and higher levels. Its usefulness to teachers at various levels of instruction needs no emphasis. It is also hoped that it will be useful to the students of all those disciplines which use graphics in one form or the other, such as economics, sociology, commerce, statistics, botany, zoology, geology and geophysics.

For a variety of reasons the book had to be completed within a short period of ten months. It has, therefore, not been possible to present it in the form it was planned. Some of the blocks have not come out well and some typographical mistakes remained undetected during the proof reading. The author hopes that the reader will forgive for the inconvenience caused to him because of these deficiencies and hopes that he will forward to him the suggestions he may have for the improvement of the book.

MYSORE
November 1, 1969 R. P. MISRA

ACKNOWLEDGEMENT

Several sections of this book are based on a few publications of the army map service of the USA. Important among these publications are *Applied Cartography, Map Intellegence* and *Map Reading*. Ideas have also been borrowed from *Elements of cartography* by Robinson, *Principles of cartography* by Raisz and a number of cartographic journals. Several of the concepts and ideas emerged from the author's discussions with Dr. John C. Sherman, Chairman, Department of Geography, University of Washington, Seattle, USA and Mr. J. W. Wiedel, Assistant Professor, Department of Geography, University of Maryland, College Park, Maryland, USA. It has not been possible to acknowledge these and many other sources at appropriate places in the book. I take this opportunity to put the record straight here.

Dr. A. Ramesh, has been responsible for writing the whole or parts of chapters 8, 12, 13, 14, 17, 18. He has shared a considerable amount of the efforts that have gone in the construction of illustrations.

My colleagues Mr. M. Salar Masood, and Mr. D. G. Jayashankar had reviewed the manuscript and read the proofs. The index was prepared by Edward A. Anjorin, a Nigerian student of the deptartment of Geography. I am thankful to them for their assistance.

I am indeed grateful to Dr. K. L. Shrimali for writing the foreword. But for the keen interest taken by Dr. Prabhushankara, Director, Prasaranga, University of Mysore, it would have been difficult to bring out the book in the time it has come. I am grateful to him and his colleague Mr. Anantaramaiah for the interest they took in its publication.

Finally, I thank my friend Shri S. R. Shivaram, Vidya Printery who took special care to print the book in time and so very well. Thanks are also due to Shri V. Madhu, and Shri C. William who had to forego their eisure to type the manuscript of the book.

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CHAPTER I

INTRODUCTION

While planning for the new geography building at the University of Mysore, I suggested the engineer to set aside a room measuring 36 feet by 24 feet for cartographic laboratory. " I can provide you with only one room of this size; may I suggest, sir, that you use it for mapping and fix the catastrophe (sic) laboratory in a smaller room ", was his reply. I was surprised and rather shocked to hear such a characterization of cartography, but the message was quite clear to me. Maps are certainly more popular than cartography, the science and art of making maps. One should not, then, be hard put to understand why this book on cartography should begin with a discussion about maps.

WHAT IS A MAP?

A map is, usually, considered to be a drawing to scale of the whole or a part of the surface of the earth on a plane surface; it is a manually drawn picture of the earth showing the location and distribution of various natural and cultural phenomena. The subject matter of maps cannot, however, be limited to the contents of the earth's surface alone. One can have maps of the heavenly bodies as well. Maps showing the location and distribution of stars and the planets are only too many to need emphasis. We already have maps depicting the surface of the moon and the days are not far off when we will have as detailed maps of the moon as we have of the earth.

A map gives a picture of one or several of the elements of the earth's surface but such a picture is not the same as a photograph. Photographs show all visible details of the area photographed irrespective of their relevance to the purpose for which they have been taken *(Frontispiece)*. The photographer has no control over the selection of the objects lying within the focal range of the camera. A photograph, no matter from which level it is taken, shows details in

their visible shapes and sizes. Moreover, a photograph shows only those objects which are physically present. It cannot, for example, represent a theoretical surface devoid of visible undulations such as income per capita or distribution of population. A map, being the mental and manual creation of man, gives only those details which its creator wants to give. Instead of showing the details in their true or visible shape and size, it uses symbols which may or may not have similarities with the shape and size of the objects represented (fig. 2).

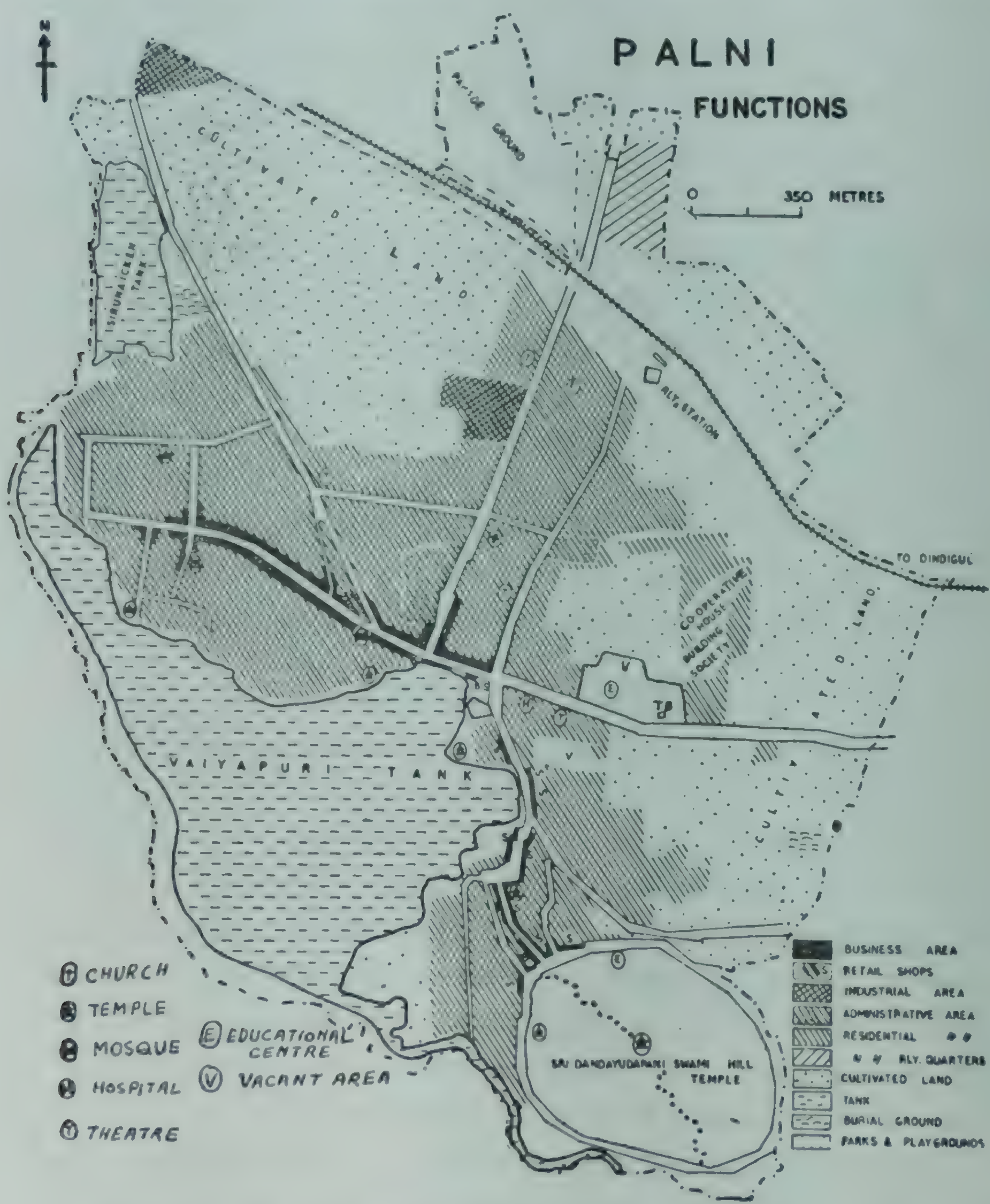


Figure 2: A map of Palni town. *(Compare it with figure 1)*

A map may also show objects or patterns which may be intangible or invisible. For example, it may show boundaries which may not be marked on the ground. It may show a pattern derived from the statistical manipulation of data but

which cannot be seen on the ground. A correct definition of maps must incorporate all these characteristics. We should, therefore, redefine a map as a symbolic drawing to scale of the visible as well as conceived locational and distributional patterns of the whole or a part of the earth, the sky, or any other heavenly body.[1]

We associate maps with the earth and not with other heavenly bodies mainly because we were not really concerned with the mapping of the latter until very recently and also because most of the maps, we see, deal with the earth and the earth alone. In fact the history of cartography shows that the scope of the term map has been earlier restricted to the portrayal of the earth's land surface alone. In such maps water bodies were shown only incidentally to maintain the desired relationships among the land masses. The maps which gave prominence to water features of the earth's surface were called charts. Charts showed the bathymetric details, water currents and other aids to navigation. Such charts are still produced and used. With the introduction of air transportation, a new series of charts, showing details useful for air navigation, have come into being. These charts are often topographical maps with navigational aids superimposed on them.

Certain maps are meant to give very minute details about very small areas like towns and villages. These maps are often called plans. For example, the city plans show the streets, railroads, water features, prominent buildings, and residential and other types of land uses. The chief purpose of a plan is to show boundaries of property ownerships and the layout of the land.

The distinction between maps, charts and plans is not as clearcut now as it used to be in the past. For all practical purposes charts and plans are also maps which portray specialized information on larger scales. It is for this reason that the term map is used in this book to include all such cartographic products.

It is the map which forms the core of cartographic representation. It is, however, not the only cartographic product. Sketches, diagrams, cartograms, graphs, three dimensional models and globes are also the products which fall within the perview of modern cartography.

A diagram is a simplified drawing designed to show inter-relationships primarily by means of lines and symbols. Some of the diagrams are highly simplified and show only the most essential elements of the data. Many diagrams are designed to give a combined effect of graphic and pictorial media for an orderly and logical visualization of the relationships between key facts

[1] For the sake of convenience we will, however, continue to treat a map as a tool to represent the whole or a part of the earth's surface in the subsequent pages of this book.

and ideas. Diagrams showing comparisons, relativeness, growth and development, processes, classification and organization are quite common.

A graph is also a cartographic product. It provides a visual representation of the numerical data by lines. A table of figures may contain a wealth of valuable information but it may mean nothing to the reader, unless he analyses it statistically. When presented in a graphical form, the data contained in the table become simple to understand. A graph reveals the interrelationships such as trends, and variations from the normal, and therefore, is inherently more interesting. At times diagrams and graphs are superimposed on maps to show the spatial distribution of the data represented by them. Such maps are called cartograms.

A rough drawing of a landscape without scale and co-ordinates and without much care for the æsthetic beauty is called a sketch. A sketch is often made of objects or areas for which pictures and maps are not available or cannot be made available readily. Sketches can be drawn hurriedly and are cheap but, at times, very valuable graphic aids. Sketch maps of unsurveyed areas are of considerable use. For explorers and socio-geographic surveyers they are indispensable tools.

Although relief models and globes are also considered to be cartographic products, they differ from others as they are not done on a plane surface. They, nevertheless, involve the same cartographic principles and techniques in their design and construction. The simulation of the real earth and its surface features in its true shape and details is the objective behind the construction of the three-dimensional models and globes. A globe represents the earth in its nearest to true shape. A three-dimensional model represents the whole or a part of the earth's surface showing the vertical relief as well.

TYPES OF MAPS

As each map is unique in its design, content and construction it is a type by itself. On the basis of certain common features, maps can, however, be classified into several types. The following are some of these types.

Types by Relief Representation :

On the basis of the amount of topographic details given, maps can be classified as :

1. Hypsometric maps, and
2. Planimetric maps.

The hypsometric maps are those which show the relief and the terrain in detail and often at the cost of other details. The large scale topographical sheets

produced by the Survey of India fall in this category. As against these, the planimetric maps give more emphasis to other details and limit the relief portrayal to the inclusion of a few spot heights here and there. Most of thematic maps representing the cultural features of the landscape fall in this category.

Types by Scale:

Taking the scale as the criterion, maps can be classified as:

1. Small scale maps
2. Medium scale maps, and
3. Large scale maps,

This classification appears to be the easiest one. The terms large scale and small scale are, however, so undefined that there is no universally accepted standard for classifying maps according to scale. What one considers to be large, may appear to be small or medium for others. The same person may consider a map to be of large scale for one purpose but of small scale for another purpose. As a result of this each specialized group of map users sets up its own standards for classification.

For the purpose of this book, maps having scales of 1 inch to a mile or 1 : 63,360 or more are classified as large scale maps; those falling between 1 : 63,360 and 1 : 1000,000 as medium scale maps and those having scales below 1:1,000,000 are treated as small scale maps. The million sheets of the Survey of India and the National Atlas of India are considered to be medium scale maps.

Types by Information:

Some maps are made to be used for a variety of purposes; certain others are made to represent one type of information; while certain others may have either of the two objectives but may be prepared for a specialized group of people having special problems of visual perception. Maps can, therefore, be classified into the following types as well:

1. General purpose maps
2. Thematic maps, and
3. Special purpose maps.

The multi-purpose wall maps, topo-sheets, and many of the atlas maps are classified as general purpose maps. Maps dealing with a single factor such as geology, rainfall, crops, population etc., are classified as thematic maps. At times a thematic map is defined as one having one theme or objective. This defininition is logical if we take the dictionary meaning of the term theme into account. But, if adopted, it will make all maps to be thematic. There is no map without a theme or purpose. One has to draw a line somewhere if the term

'thematic' has to be used meaningfully. It is, therefore, suggested that the use of this term may be restricted to those maps only which represent only one type of data such as population and in which other types of data are either not given or given to highlight the basic data. Thus a population map showing physiography in the background will be called a thematic map. The special purpose maps are those which are constructed for a group of people having special reading or perceptual problems. Thus the maps for the blind fall in this category. Similarly, the maps for the children and neo-literates are also called special purpose maps.

Types by Military use:

There are certain maps which are drawn specifically for the use of military personnel. From a soldier's point of view, maps can be classified as :

1. General maps
2. Strategic maps
3. Tactical maps, and
4. Photomaps.

Any map on a scale of 1 : 1,000,000 or more is considered to be a general map. General maps depict only the broad topographic features and are usually used by the high command for general planning purposes. Maps having scales ranging from 1 : 1,000,000 to 1 : 500,000 are often classified as strategic maps. These maps are used for the general planning of more concentrated military effort. Maps with scales of 1 : 500,000 or less are called tactical maps. A tactical map serves as a guide to small units like battalions and patrol units prior to and during the movement anywhere near the front line. These maps show almost all the relief and planimetry and hence, are used in planning the tactics of smaller combat units. At times maps having scales of 1 : 250,000 to 1 : 500,000 are classed as strategic-tactical maps. These are mostly transportation and communication maps with relief and planimetry shown on them. They are used mainly for logistic planning and operations involving infantry and armoured corps.

A photomap is an air photograph with strategic and tactical data superimposed on it. It is not a map in the true sense of the term; it is rather a map substitute. Because of its wide use in the theatre of operations, it has, however, been discussed here. A photomap may constitute just one photograph or it may be a mosaic composed of several of them. The scales of the photomaps range from 1 : 5,000 to 1 : 60,000. As the photomaps show the details against their photographic image, they are easily comprehensible to army personnel. There is, therefore, a strong tendency among the troops to use these maps.

MAPS HELP US IN MANY WAYS

Maps have become so much a part of our life that we cannot dispense with them. We often need them to find the location of a place. We certainly need them as visual aids in our class rooms. They have already proved their worth as indispensable tools for the synthesis and analysis of distributional data. The urban and regional planners make their use to unravel the planning problems and to show the progress made. By giving a visual and integrated picture of the areal — intra-national as well as international — disparities in the development of natural resources, social, political and economic developments, they influence national integration and international cooperation. Certainly a well-done map is worth hundreds of pages of a book in many respects.

Location of places:

The most universal use of maps is for locating places and things. Location of an object involves the knowledge of the site i.e., the precise geographic location and the situation or its location in relation to surrounding features. As the geographic mobility of the people increases, the use of maps for locational purposes also increases. In the United States of America one cannot find a motorist without a pack of road maps. The use of such guide maps is catching up in other parts of the world also.

Education and Research:

Maps are useful, and at times indispensable, tools for the teachers and the students of all those disciplines which have something to do with the distribution of natural or cultural features on the earth's surface. One is only too well acquainted with wall maps as class-room visual aids in teaching. Many books contain maps as textual illustrations. Good maps save thousands of words and have the capacity to crystalize the facts and figures in a fashion which makes them comprehensible and clear. The burden of the students will certainly be lightened if the advocates of various disciplines reduce some of their circumspect discussions to simple map terms.

The usefulness of maps as research tools is now well recognized. It is evident from the fact that most research institutions concerned with the study of socio-economic problems of our society have a cartographic laboratory attached to them. Maps highlight the problems and present a picture of the problem as well as the progress made in a fashion which is easy to understand. Use of statistical and quantitative techniques in processing of data to be represented on maps has further increased the utility of maps as research tools. The net result of this development is the increasing number of thematic maps.

Planning and Development:

Maps can be and are of considerable use in planning socio-economic development of a community, a region, or a nation. While planning for a community such as a village or a city, the present, past and future land use patterns must be depicted on maps. The existing property ownership lines must be marked accurately. The jurisdiction of the planning authority must be shown clearly. The density of population in different parts of the community, the educational and recreational facilities and the shopping centres must be planned on the basis of the needs of different areas. Industrial and residential locations should be planned by taking into account the transportation, sanitation, education, recreation and other facilities. Each of these factors can be represented on maps which afford clearer visualization of their interrelationships. There is no better way of describing them.

Maps are equally useful in regional and national planning. Regional plans often cover areas far beyond the confines of the service areas of the urban or metropolitan centres. The potentialities of development can be gauged by a clear understanding of the location and distribution patterns of the natural and human resources and the existing social overhead capital. No other medium can do it better than a map. In the same way maps are useful in showing the progress made in different parts of a region or a nation. The usefulness of maps in this respect is well indicated by the fact, that the United Nations Organization has taken up the preparation of an international series of landuse maps and almost all important countries of the world have taken up the preparation of National or Planning Atlases.

Military Strategy:

Not many of us realize that wars and conflicts among the nations have been the greatest promoters of map production. No war, big or small, can be executed efficiently without the help of good maps. During the world war II the Army Map Service of the U. S. A. alone produced about 40,000 different maps and distributed a total of over 500 milion copies of them. A single movement of troops requires several different types of maps; and when the operation involves a combined effort from all the branches of the armed forces, the variety of maps needed further increases. The land forces need one type of maps, while the air forces the other type and the naval forces a third type.

More often than not, military operations have to be carried out in areas which have not been visited by the armed forces before. These forces have to know the details of topography so exacting as to be able to locate the mounds, canals, ditches and wells, to name a few. No amount of verbal desciption can do the

job. Many operations have failed mainly because of the lack of good maps. One of the factors responsible for India's defeat in 1962 in NEFA was the lack of accurate maps.

Other Uses :

In recent years the uses of maps for propaganda and advertising purposes have increased to a great extent. Maps are also being increasingly used by aero-space science. The use of mapping techniques to represent the surface of moon and other planets and to show the movement of satelites and rockets are examples of new uses of cartographic products.

Maps are certainly of great use to us. We should, therefore, know as much about maps as we can. But knowing maps involves knowing about cartography – the science and art of making maps.

CHAPTER II

NATURE AND SCOPE OF CARTOGRAPHY

Cartography is generally considered to be the science and art of designing, constructing and producing maps. It includes almost every operation from original field-work to final printing and marketing of maps. The scope of modern cartography is, however, not limited to these processes alone. It is also treated as a science of human communication.

At times the term 'cartography' is used to signify only the mechanical aspects of drawing maps. Such is often the case in India where a graduate course in cartography is considered to be co-terminous with a course in practical geography. Actual drawing is however only a portion of the total scientific, technical and artistic efforts that are needed to bring out a map. The processes of designing a map and manipulating its various elements to suit the heterogeneous needs and fancies of the users demand skills which are more fundamentally cartographic than the skills of making original drawings. Of no less significance are the skills related to cartographic planning involving the coordination of the entire map making process.

Apparently, a good map can be produced only by a judicious blending and proper coordination of the scientific and artistic skills that go into its production. In the present context of map production processes, the supremacy of the former is, however, unquestionable. The scientific training and the academic background necessary for planning, designing, and executing a map are certainly much more difficult to acquire than the manual skills needed to convert a well thought out map into a well-drawn map. With the increasing number of draftsmen who can make fair drawing under the supervision of a cartographer, without knowing much about why a map has been designed in a particular way, the theoretical aspects of cartography have acquired considerably greater importance in recent years. One can be designated as a cartographer even though he

may not have the manual skills for drawing maps, but a good draftsman without the intellectual and technical skills needed to plan and design a map cannot be called a cartographer.

It does not, however, mean that the artistic aspect of cartography are now de-emphasized. Instead they are given as much importance as the scientific aspects of it. It does, however, mean that the emphasis now rests on the aesthetic sensibility and the principle underlying the creation of a work we call artistic rather than on the manual skills of making fair drawings. These points will become clearer as we further discuss the nature of cartography.

ARTISTIC LEANINGS OF CARTOGRAPHY

Since the aim of cartography is to improve the graphic representation of the earth, it cannot avoid being partly artistic in nature. A map not only portrays details visually in accordance with certain scientific principle but also in a way that is pictorial and aesthetic. The study of cartography is, therefore, partly a study of map graphics. The cartographic methods of representation and exposition follow the same principles and laws which underlie other types of graphics. And since art is the highest form of graphics, a good map cannot afford to be non-artistic.

To what extent cartography is an art is a controversial question. There are cartographers without much artistic skills, there are also cartographers who are artists first. There can, however, be no cartographer who does not have a sense of beauty, proportion and order. And anyone who has this sense can aspire to become a cartographer.

The purpose of cartography is not the same as that of art. Cartography does not aspire to produce the greatest work of art. We have yet to know a map which has been given a place in art galleries as a masterpiece of art. Art and artists require complete freedom of expression; they, often, utilize this freedom to create a piece of work which may be incomprehensible or even meaningless to the common man. Unlike an artist, a cartographer functions under severe limitations set by topographical and statistical details, symbols and colour standards. Moreover, a cartographer can never afford to create a piece of work that will be incomprehensible and meaningless to its users. A piece of art is valued for its aesthetic beauty and sensibility whereas a map is valued for its mundane utilitarian values.

But if one defines beauty not only in terms of visual expression and artistic sensibility but also in terms of a sense of proportion, harmony of form and colour and simplicity, a well-done map is always a piece of art. A good map requires a high degree of legibility; it requires expession by methods

emphasizing the pertinent and supressing the less important or irrelevant; and it requires a well balanced harmonic interaction between the individual elements of a map. It is in this sense, and in this sense only that cartography can be said to be an art.

SCIENTIFIC BASES OF CARTOGRAPHY

As a discipline interested in devising ways and means of bringing order and system, generality and simplicity, refinement and legibility and ease of use and comprehension to an almost incomprehensible range of complex details through a medium which we call map, cartography is a science that has its own individuality. It is a science with artistic leanings. It can be well compared with architecture in many respects and may be characterized as a technical science. But it is something more than a technical science.

In the first place cartography is a geographic science. The subject matter of cartography is the surface of the earth and to a certain extent the *heavens constituting* the planets and the stars. It seeks to represent them as realistically as its principles and rules permit. To be successful in his endeavours, its *practitioner* must get a first hand knowledge of the earth either by observation or by study. He must know well the spatial distribution and location of various objects, because maps show the location or distribution of various objects at their appropriate points according to a given scale. Cartographic representations also involve the selection of the important and the rejection or supression of the unimportant. A cartographer, thus, has to generalize the data. Generalizing the cartographic data is, however, as difficult as generalizing any other data. It involves prior knowledge of the elements to be generalized and a training in reasoning and synthesis. Cartography is, therefore, a geographic undertaking and a cartographer is a graphic geographer or geographic illustrator.

In the second place cartography is an auxiliary science which acts as a bridge between techniques, art and earth sciences. As a map is a generalized picture of the earth surface the cartographer has the difficult task of generalizing the complex details of this surface. To do this successfully, he has to have the background of not only geography but also of other disciplines in which he essays to prepare maps. Cartography is, therefore, a science which entails cooperative efforts of specialists in a variety of fields. The geodetist and the topographic surveyor give the size and shape of the earth and the location of its surface features; the economists, sociologists, geologists, botanists etc. give the subject matter. The cartographer classifies and generalises these details and converts them into mapable form. He also designs and draws a map which the printers use to produce a number of identical copies.

This description may give an impression that various cartographic processes can be carried out independently by different disciplines. But this is rarely the case. The surveyor not only surveys but also draws. His field drawings are then used to compile maps on smaller scales. The number and the size of the original drawings to be made depend upon the colour scheme of the map and the printing process to be used. The financial resources also limit the freedom of action on the part of a cartographer. It is because of this interdependence of the various cartographic processes that most official mapping agencies in the world combine all these operations from original surveys to drawing, printing and marketing of maps. A writer can be easily separated from the printer of his book, but a cartographer cannot be separated from his map printer. The two have to work together.

The above discussion, points to the conclusion that cartography is neither an experimental science like physics or chemistry nor a social science like economics or sociology. It is a scientific discipline which employs scientific methods and logic.

CARTOGRAPHY AS A SCIENCE OF HUMAN COMMUNICATION

The ultimate purpose of cartography is to communicate facts and ideas clearly and forcefully through a combination of drawings, words, and symbols. It is distinct from other forms of graphics in the sense that it specializes in communicating facts and ideas about the earth and earth alone. Many cartographers certainly prepare maps to satisfy their own intellectual curiosities. Like all creative activities cartographic endeavours give inner satisfaction to the creater no matter whether others appreciate them or not. But such maps are very few. Most maps are made to communicate facts and ideas in which people are interested. And hence the success of a map is often determined by the effectiveness with which it is able to convey the message. Viewed in this way map becomes a mediu of communication and cartography a communication science. The author will, therefore, venture to say that one of the main purposes of cartography is the communication of the facts and ideas about the earth. This may be disputed by many geographers and cartographers who would feel that it is the representation of the earth that is important and not the communication aspects of it. Perhaps such an objection would have been valid in the past when we did not know much about the shape, size and surface contents of the earth, when major portion of the earth was left unsurveyed and when the geographer was an explorer chiefly interested in telling the people of his new discoveries about the earth. That time is no more with us. We are now well

aware of the shape, size, and contents of the earths surface. In fact we are now gradually getting interested in the moon and other planets and satellites of the solar system. In this context the role of cartography has to change. Cartography should concern itself more with the effective portrayal of the facts and ideas about the earth than hither to done. When we talk of effective representation we talk of effective human communication.

The process of human communication is indeed a complicated one. Here an attempt is made to give a simple description of this system and to introduce the readers the role of cartography in this process. A communication system may be considered to have five elements. There is a *source* and a *destination* for a message. Between the source and the destination there is a link enabling the message to span the distance. We may call this link a *channel*. To allow the information to pass through the channel it must be encoded in a language which can be transmitted through the channel. The component which does this encoding is called the *transmitter*. And at the other end there must be a *receiver* to reconvert or decode the message into its original form before it reaches the destination. These five elements i.e. *source*, *transmitter*, *channel*, *receiver*, and *destination* constitute a communication system (fig. 3).

Figure 3 : Elements of a communication system.

An ideal communication system functions something like this. The transmitter gets a message from the source. He encodes this message into a language that can be fed into the channel selected for the transmission of the message. At the other end the receiver reads this message and decodes it into a common language.

The likelihood of a message reaching the destination depends upon a variety of factors. The first is the nature of the message itself. A clearly stated message coming from an authentic source will have a better chance of reaching the destination than the one which is ambiguous and has emanated from an unreliable source. The second is the efficiency with which the transmitter encodes the message. The third one is the noise or disturbance in the channel itself, and final one is the attitude of the receiver and his ability to decode the message.

If we apply this system to cartography we will have the following arrangement :

1. Information Source	All the natural and social sciences concerned with the study of earth and its surface features.
2. Message	Ideas and facts about the earth and its surface features; also about the heavens and heavenly bodies.
3. Transmitter	Cartographer who converts these ideas and facts into words, drawings and symbols.
4. Signals	The words, drawings and symbols and their mutual arrangement.
5. Channel	Maps and other cartographic products.
6. Noise Source	Poor design or drawing, cluttering of the symbols, incorporation of unnecessary facts to the detriment of the relevant ones, poor printing etc.
7. Received signals	Symbols etc. as perceived by the map user.
8. Destination	Map users the world over.

A cartographer has to remain sensitive of the reactions of the users of his products and has to make use of these reactions to modify and improve them. He has to so develop his products that they assist the users in clearly perceiving the facts about the earth.

Our preceptor sensory mechanisms are in continuing contact with the real world of things and events. The eyes, the ears, and the nerve endings respond to a variety of stimuli as temperature, pressure, odour, and taste. They are the means through which almost all learning and understanding is accomplished. They are the means of perception. When we perceive something, we translate impression made upon our senses by stimuli into awareness of the objects or events perceived. We construct our world of things and events out of our sensory process and the physical objects, as we know them through sight, sound, taste, smell and touch.

Understanding results from coordinated perception which is the outcome of multiple impressions recorded through the sensory mechanisms. Lack of any sensory receptor eliminates the possibility of complete perception. we cannot acquire a perfect knowledge of the earth and its surface features unless we are in a position to see it with our eyes also. Reading and listening give only half the truth. Observance gives a real experience and associative feeling.

Observation of the whole earth with all its minute details and patterns being impossible, man, from the very beginning of his civilization, developed means of portraying it cartographically. A map is a model of the earth or a

portion of the earth. It is a graphic model. It gives a more realistic picture of the earth than any verbal description can give.

Maps stimulate thinking and understanding about the earth; they also lay the foundation for attitude formation. Attitude is a mental and neural state of readiness, developed through experience with persons, things and events. It has a directive or dynamic influence upon our response to all those objects and situations with which we come in contact. Our attitude towards other parts of the world depends upon this state of readiness developed through experience with the real world. It can be changed by carefully planned learning situations. Maps are the means through which learning situations can be changed to create a better understanding of the physical and cultural contents of the world. Cartography, the science and art of making maps, is, therefore, a science of human communication too.

BRANCHES OF CARTOGRAPHY

Because of its wide scope and distinguishable, though not separable, functions, cartography is often considered to have two branches. These are theoretical and applied cartography. In the recent past, a number of other sub-branches such as aerospace cartography, journalistic cartography, geographical cartography, thematic cartography, statistical cartography and scientific cartography have come to light. Such sub-divisions do indicate an increasing trend of specialization within the general field of cartography. They also indicate an increasing interest in cartography and its products. The basic principles and the techniques underlying all these so-called sub-divisions are, however, the same and hence only minor or no adjustments are needed to become one or the other type of cartographer. It is for this reason that all these aspects of cartography are not discussed here as separate branches.

Theoretical cartography deals with the conceptual and theoretical aspects of cartography, such as the critical testing and further development of map design and content, of the graphical methods of representation, of the ways of formulation and the establishment of operational standards and of the principles of map editing. A theoretical cartographer tries to keep in touch with the map users to know their future requirements and their reactions to the available maps. He tries to devise and design maps which meet the requirements of the users and at the same time function as effective media of visual communication.

Applied cartography includes such functions as the laying out and final drawing of maps. It functions within the framework of certain rules,

standards and guidelines set by theoretical cartography. It is also concerned with the development of improved methods of drawing and reproduction of maps. Instrumentation and automation, therefore, fall within the perview of applied cartography. Topographical and socio-geographic surveys also are considered as aspects of applied cartography.

The major field of applied cartography is the technique of actual drawing of maps. It may and should include the application of cartographic techniques to other disciplines and problems also within its perview. An applied cartographer takes interest in researches leading to the application of cartographic methods in the solution of many of the problems that our society faces today. He helps the planners, the extension agents and teachers in communicating their ideas and views to their clients.

CHAPTER III

HISTORY OF CARTOGRAPHY

The history of cartography is largely the study of the increase in the accuracy and effectiveness with which the tangible as well as the intangible contents of the earths surface are measured and portrayed on maps. The scope of cartography has, therefore, been directly linked with the knowledge about the earth. During pre-historic times, man kept this knowledge in his mind for it was too little to need recording. Nor there was a readily available technique of recording this knowledge. Even today our so-called primitive people carry mental maps of the areas in which they live or hunt.

But with the passage of time mental maps proved to be inadequate because the horizons of the world expanded beyond the neighbourhood, community and hunting area. Gradually the whole of the earth became the stage on which man started playing the drama of life. Man was rather forced to develop a variety of techniques and means to keep the records of his experiences for posterity. Cartography is one of these many techniques. The history of maps and of all that they have meant to mankind is, therefore, as vast and old a field as the history of art or literature. And the hundreds of thousands of maps which have come down to us, have within them an invaluable record for those who are interested in exploring the man's past.

As the subject matter of cartography has changed through time so also have its functions. In the past it was more concerned with the measurement and the representation of the shape, size and other broad details of the earth's surface. Today these broad details are well-known to us. We have at our disposal minute details of the contents of the earth's surface. Our problem is to analyse these complex data and to present them in a form comprehensible to map users. Modern cartography, therefore, functions more as a graphic science representing the details of the earth's

surface rather than as a science engaged in the measurement of the shape and size of the earth.

Like modern science and technology, modern cartography appears to be essentially of Western origin. It represents a phase in the development of cartographic tradition that stems from ancient Greek times. About the origin of Greek cartography, we do not know well. It might be that it owes its origin and fulfilment to the developments in other preceding or contemporary cultures of Southeastern and Western Asia. But the available historical facts are not strong enough to give evidence in favour of such a hypothesis.

On the basis of the existing knowledge about the historical development of cartography four distinctive stages may roughly be marked out. These are ancient period (upto 400 A.D.); medieval period (400 to 1500 A.D.); early modern period (1500 to 1900 A.D.); and recent period (1900 A.D. to date). The above stages should not be treated as discrete. There have been periods of retrogression and stagnation, interrupted by others of rapid development, during which outmoded ideas have held their place beside the new. Further, the theoretical knowledge was not closely followed by its application. Thus many of the processes cut across these stages.

THE ANCIENT PERIOD (UPTO 400 A.D.)

This period may be studied under the following heads:

1. Primitive cartography;
2. Greek cartography;
3. Roman cartography; and
4. Asian cartography.

Primitive Cartography:

A visit to any good ethnographic museum proves beyond doubt that graphics is not a science of recent origin. Even the most primitive people expressed their ideas and experiences graphically. Primitive people like the Eskimoes of the Arctic, the Bedouins of the Arabian desert, the Polynesians of the Pacific islands, and the Banjaras of India, have a remarkable ability to draw sketches of the areas with which they are familiar. Such maps drawn on a piece of skin, wood, bone or terracotta indicate the relative position and distances of localities known to them. It appears that such activities were quite common among the early inhabitants of Southeast-Asia and Western Asia including those of Eastern Mediterranean. As these ancients improved their cultural heritage, they started producing better maps — maps which were used as tools to solve

certain problems of day-to-day life. Egyptians used geometrical methods for land measurement and for establishing land ownership lines after each flood in the Nile. These lines were shown on cadastral plans. Many of such plans included specifications for the construction of temples, palaces, canals and roads. Such maps were produced not only by the Egyptians, but also by the Babylonians, the Chinese, the Aztecs and the Incas.

Although the mapping of this nature showed a definite improvement over the one practised by their predecessors, the range of its coverage was still limited to the earth with which the people were concerned and not to the earth as it was. To them the earth was not only flat but also infinite in the sense that beyond their own territorial limits, lay unknowns of various types. The first were the Babylonians who gave some thought to the shape and the size of the earth as a whole. They believed the earth to be flat and circular surrounded by sea and heavens.

Greek Cartography:

Ionians were the first Hellenic people to take interest in the development of scientific thought. They had an advantage of being close to Babylonians who were pioneers in the field. Moreover, the pressing socio-economic conditions and at times disturbed political conditions forced them to pay greater attention to the world beyond their own sphere of influence. They developed trade relations with far lying areas. They prepared itinerary maps showing the stages along the routes leading to such trading areas and centres as the coasts of Mediterranean and Susa the capital of Persia. By 600 B. C. they established maritime settlements from east coast of Spain to the far reaches of the Black Sea. They established a number of ' city states '. These city states maintained close relations with the mother cities in Greece. These relations opened up new opportunities for knowing more about the world beyond and to speculate about the shape and the size of the earth and the causes of the physical world.

By 600 B.C. the Greeks had developed Miletus as a centre for geographical studies and cosmological speculations. One of the early products of this centre was Thales who is considered to be the founder of natural philosophy. Anaximander who prepared the first map of the world (as known at that time) and Hecataeus who wrote the first book of geography also came from this centre. Hecataeus believed the earth to be a circular plane, surrounded by continuous belt of ocean with Greece in the centre (fig. 4). Another general principle which governed much of Greek thinking was the symmetry in nature. So that in the maps of Anaximander one finds a balance in the features shown north and south of the axis. A generation later, Herodotus, who was himself a great traveller

Figure 4: Outline of the world map of Hecataeus.

and who knew the circumnavigation of Africa by the Phonecians and the voyage of Scylax down the Indus, further improved the world map and showed Caspian sea as an inland sea. He did not represent the earth to be circular. He also did not show the northern ocean (fig. 5.)

With the further expansion of the known world through the military and sailing expeditions which Greeks organized, a mass of facts was available for the use of later cartographers. Important among these were the sailings along the Atlantic by the Carthaginians, along the west African coast by Hanno, along the Spanish and Gaulish coasts by Himilco, and the campaigns of Greek mercenaries against Persia and of Alexander against India. Meanwhile the idea that the earth was not a flat disc but a sphere, as advanced by the philosophers of Pythagoras' school and as propagated by Plato, got wider recognition.

As new data were pouring in, the centre for scientific studies was gradually shifting to Alexandria. It was here that Eratosthenes measured the circumference of the earth being 24,662 miles, only a few hundred miles short of the correct measurement. Unfortunately this measurement was not accepted by his successors. Eratosthenes also tackled the problem of representing the spherical

Figure 5: Outline of the world map of Anaximander.

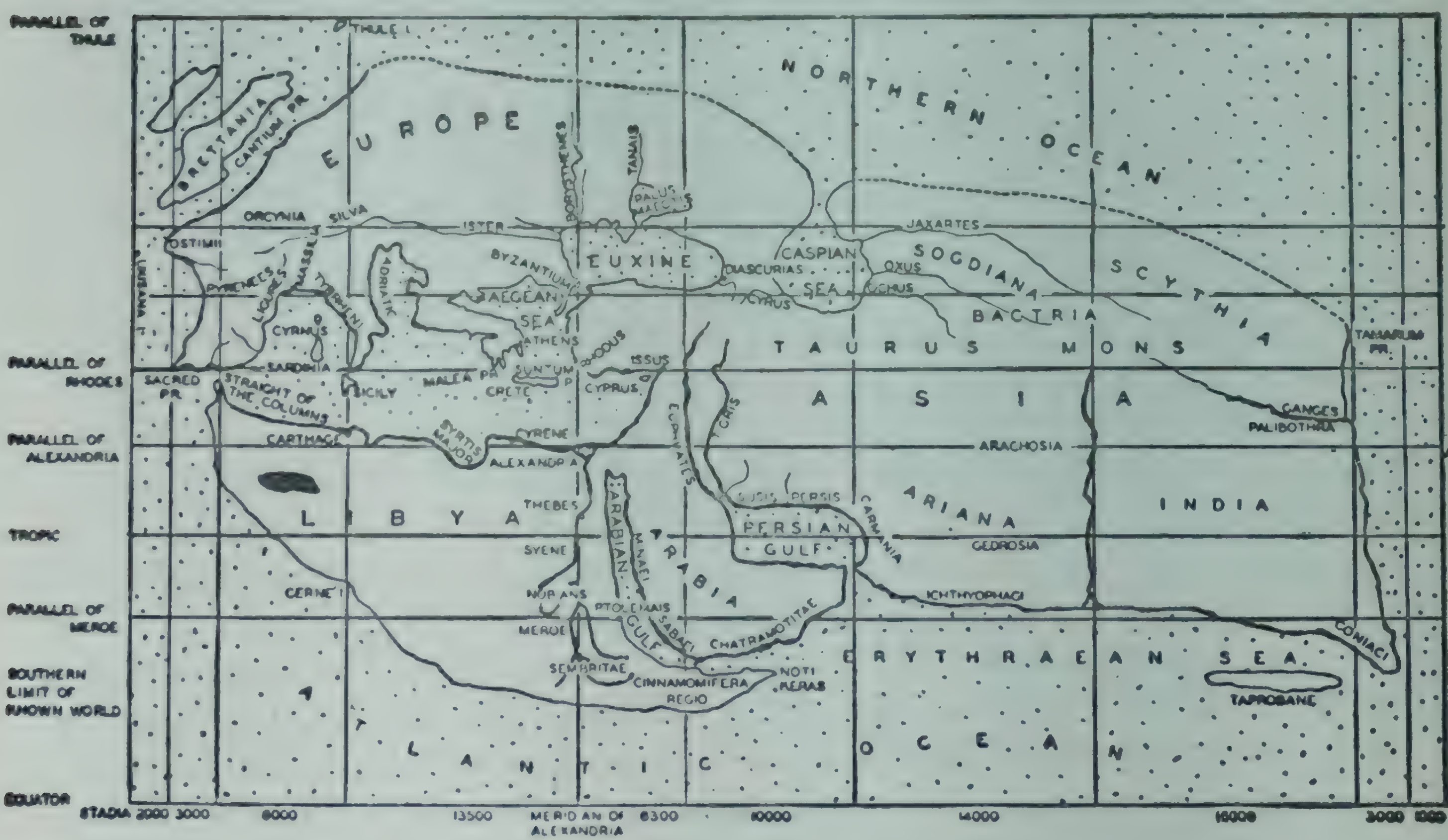


Figure 6: Outline of the world map of Eratosthenese.

earth on a plane surface by extending two parallels eastwards, one passing through Gibralter and the Caspian sea and the other through Egypt and south India. He also established the zero meridian approximately following the Nile but starting from the mouth of river Don (fig. 6). Later on, the ground work prepared by him was challenged and improved by Hipparchus who compiled a table of latitudes. He proposed a scheme of 360° of latitudes and longitudes but it could not be given effect to for want of appropriate apparatus and instruments which could give necessary astronomical data for the purpose. Nevertheless, he laid the foundation for scientific cartography upon which Ptolemy built his concepts further.

Between Hipparchus and Ptolemy came a period which is known as Posidonian period. The period is named after Posidonius who led the Greek thinkers to pause and consolidate the progress already made. This period thus became the period of compilation. The compilations of this period were used by the Romans in constructing their maps. The Romans in turn transmitted this handbook information to the Latin countries of Europe, resulting in the stagnation of cartographic progress until the Rennaissance. Even Ptolemy based much of his work on these compilations. He rejected Eratosthenes' calculations of the circumference of the earth and preferred Posidonius' estimates. His estimates were used as late as 15th century A.D. Strabo's Geography in 17 books is one of the several works of this period.

The development of geography at Alexandria reached its pinacles during the second century A.D. It culminated in the contributions of Claudius Ptolemy. Ptolemy released his "Geography" in 8 volumes. The first of these volumes deals with the principles of mathematical cartography and methods of representing a spherical surface on a plane surface. The other books give the location of places or features of geographical interest. There are twentysix regional maps and one world map attached to his book. In addition to these, sixtyseven maps of smaller areas are also given. One finds several inconsistencies between the text and the maps. It has, therefore, been doubted whether the maps were done by Ptolemy or some one else. As no manuscript older than twelveth century A.D. is traceable, this doubt does not appear to be baseless. It is now widely believed that the maps were not drawn till the thirteenth century.

Ptolemy miscalculated the circumference of the earth to the extent that his one degree of latitude was equivalent to $56\frac{1}{2}$ miles in contrast to Eratrosthenes' $68\frac{1}{2}$ miles. Thus when converting distances into degrees, he got greatly exaggerated figures and the east west extension of his world became too long. His concept of Asia was erroneous as he overlooked

Peninsular India and estimated the size of Ceylon several times larger than its true size. He also showed Indian ocean as a land-locked water body. He committed similar mistakes in the representation of south-east Asia and north Africa (fig. 7). All these mistakes were carried forward by later geographers and cartographers and had to do much with the slow rate of growth of cartography in the centuries that followed.

Figure 7 : Outline of the world map by Ptolemy.

Roman Cartography :

As against the Greeks, the Romans did not take much interest in Scientific Cartography and they seem to have been singularly unconcerned with the Greek achievements in the field. For a long time they were concerned with the expansion and consolidation of their empire and hence only those maps which assisted them in this endeavour were favoured by them. Thus a map for them was a practical tool to be used in the travels of the officials and the campaigns of their armed forces. Their maps showed the road networks and the battle fields and many of them were nothing more than geographical renderings of written records. The 'Peutinger Table' is an example of this type of work. It was prepared during the 3rd century A.D. For all practical purposes it is a road map of the Roman empire. The roads are shown by straight lines and the distances between any two stages are marked. As true directions are neglected, the shape and relative positions of various features are considerably distorted. It includes Europe, Africa and Asia and contains 534 illustrations, 311 for Europe, 62 for Africa and 161 for Asia.

Another contribution of the Romans was the famous Orbis Terrarum or 'Survey of the World' prepared by Marcus Vipasanius Agrippa in 12 B. C. This map was displayed in Rome for the information of citizens and appears to have contained much greater details than the Table. This is confirmed by Pliny in his 'Natural History'. The probable shape of the map was circular (fig. 8).

Figure 8 : Outline of Orbis Terrarum of the Romans.

Indian Cartography (Ancient times to 800 A. D.) :

As stated earlier it is not yet known as to whether map making was practised in ancient India or not. It is, however, now well known that the knowledge about the universe and the earth was quite advanced in India in ancient times. The basic foundation of this knowledge was laid during the Vedic period when general expressions of astronomical truths and cosmological revelations were made. During the Siddhantic period that followed these expressions were crystallized into Siddhantas or laws. The post-Siddhantic period gave rise to classical treatises by great astronomers like Arya Bhatta, Varahamihira, Bhaskara and others. In addition to these, there were works on positive sciences like the Bhouthika Sutras which gave astronomical as well as terrestrial details.

Many of the revelations in the ancient literature point to the conclusion that some of the so-called discoveries by the West were known hundreds of years before in India. For example, Arya Bhatta discovered the relative movement of the earth and the sun, a clear thousand years before Copernicus.

Even earlier, the Aitareya Brahmana said " the sun never sets or rises; when people think that the sun is setting, he only changes about after reaching the end of the day and makes the night below and day to what is on the other side." The Bhoutik Sutras stated that the sun was fixed relative to the earth and that the earth was round like an egg. Saunaka calculated the earth's distance from the sun which surprisingly approximated the modern estimates. Bhaskara calculated the circumference of the earth to be 24,385 miles, diameter 7,905 miles, and the surface area 396,325,850 square miles. He also estimated the atmosphere to extend to a height of over 60 miles.

Knowledge about the world appears to be quite extensive in ancient India. It appears that the whole of Eurasia and parts of Africa were frequently visited by our ancients. The whole of the known world was divided into seven dwipas or regions. A map showing the location of these regions is given in fig. 9.

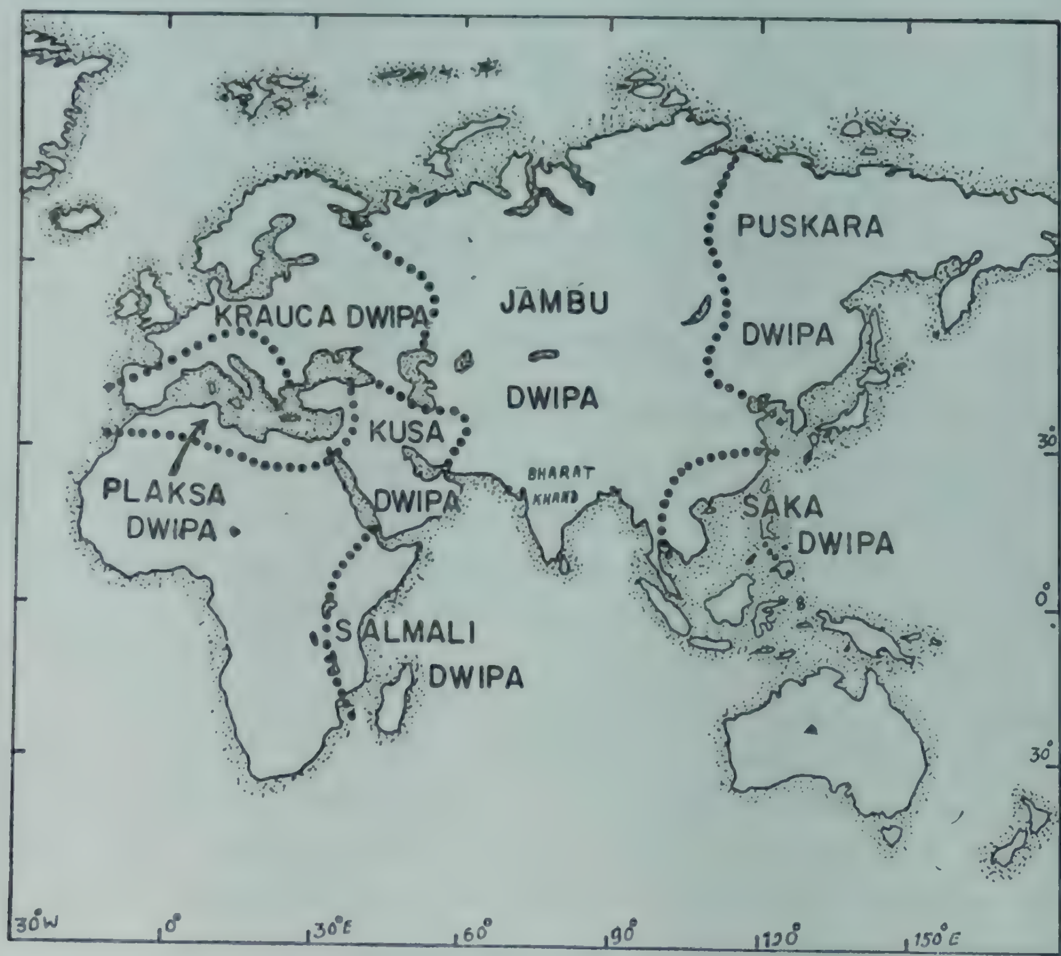


Figure 9 : Dwipas of the world as known to the Indians (After S. M. Ali).

The world as a whole was undoubtedly considered to be round and surrounded by water. The southern waters were considered to be salty

whereas the northern ones to be milky. This was the position during the Mahabharata time. But prior to that all oceans were considered to be salty. A diagrammatic representation of the world as conceived at the time of Mahabharata is given in fig. 10. One interesting feature of this conception of the world is that India was not put in the centre of the earth. The Meru or Pamir Mountain was considered to be the centre.

Figure 10 : World as conceived by Indians during the Mahabharata times (After **S. M.** Ali).

The maps showing the Dwipas and the World and the study of the names of the rivers and mountains as given in ancient literature prove beyond doubt that our ancients had frequently visited Europe, Russia, and other parts of the old world. But none of those discoveries appear to have been recorded cartographically. It is possible that even if such records were there, they could not survive the ravages of time. But the fact remains that the knowledge of the world in India was far advanced than in Greece or Rome before the Christian era.

South–East Asian Cartography :

To what extent had cartography developed in other Asian countries during this period is not known. It is believed that maps of one sort or the other were prevalent in China, India, Japan and Korea. Considering the large extent of migration of the people of Asia from one region to another it is doubtful that the routes to be followed and the countries to be visited were not well known. There is every possibility that the intervening seas and oceans were also well charted by the Chinese and Indians.

EARLY MEDIEVAL PERIOD (400 A.D. TO 1200 A.D.)

During the early medieval period geographical knowledge in Europe was standstill. Maps and the data already recorded were further manipulated during this period without verification and more errors were introduced in them. Cartography became a copy work of existing maps. Most of the maps of this period are the so called T–O maps. These maps were oriented with the east at the top. O represented the circular world whereas the horizontal and the vertical strokes of T represented Don-Nile meridian and the axis of the Mediterranean respectively. Some of the maps of this period were rectangular but with same details as in T–O maps. This innovation might have been brought in to accommodate the Christian view of a four cornered world.

It is interesting to note that the notion of the earth being round as enunciated by the Greeks was used by cartographers of this period. The maps of this period, practically without exception, showed the earth as a flat disc. The main type of circular world map of this period i.e. *Mappa Mundi* was a modified form of the world map of Agrippa. And the modifications were made at the instance of the Christian theologians, so that Jerusalem was shown in the centre of the map and the area of Palestine was considerably enlarged to accommodate minute details. The empty space was filled with neatly represented themes from the contemporary history.

The above facts prove beyond doubt that Ptolemy's geography exerted almost no influence on the early medieval Europe. It, however, did have some influence on the Byzantine and Arab cultures. The text of ' Geography ' by Ptolemy was translated into Arabic in the 9th century, and its maps were well known to the Arab scholars like Masudi. In the twelveth century Idrisi compiled a world map using Ptolemy's map as one of the sources. His other sources were the Arabic sailing records and his own knowledge of the world. Similar advances were made in the Far Eastern world too. Chinese had

developed mariner's compass, and notable advances were made in India toward the calculation of latitudes and longitudes. But the details of such advances are still unknown to us. During this period India's contacts with South-East Asian countries increased tremendously so that more detailed knowledge of the Bay of Bengal and South-East Asian countries was available. It has not, however, been proved yet that this knowledge was ever used to make a map.

LATE MEDIEVAL PERIOD
(1200 TO 1500 A. D.)

By the end of the 13th century the use of mariner's compass and the construction of charts giving navigational aids to sailors had become quite common. The Italians were the leading cartographers who made such charts. These charts are often referred to as Portolan charts. About twenty of these charts have survived to give us a glimpse of the state of cartography during the 14th century. These charts were made on the skin of parchment measuring 36×18 inches to 56×30 inches. The coastlines and the names except the names of important harbours were usually given in black. Islands, rivers deltas, rocks and shoals were shown in red. Land details were extremely few and the design was decorative. They were drawn to scale but the units of measurement were not given. Most of these charts show coastline of the Mediterranean and Black seas and part of the European coast of the Atlantic, with some accuracy, but representation of the coasts beyond these limits is full of inaccuracies. Even the Baltic coast has been shown very crudely.

The charts do not show the latitudes and the longitudes. The sphericity of the earth was also not taken into account in their construction. The area covered by these charts being small, this deficiency did not create any large scale error. They did, however, show a system of lines radiating from two chief and several subsidiary centres. These lines showed the approximate compass directions (fig. 11).

These charts were later improved as more detailed surveys were carried out. This is clear from the fact that the charts prepared subsequently were more accurate. For example, in Carte Pisane (late thirteenth century) Britain is represented in a very crude form but in Perrinus Vesconte's outline of 1327, the representation of the coastline of southern England is considerably improved. By the begining of the fourteenth century the Catalonians mainly Majorcans took over from the north Italians as leading cartographers. The Majorcans revived the classical interest in Asia. This revival is embodied in the Catalan world maps published in the Catalan Atlas in about 1375 A. D. (fig. 12).

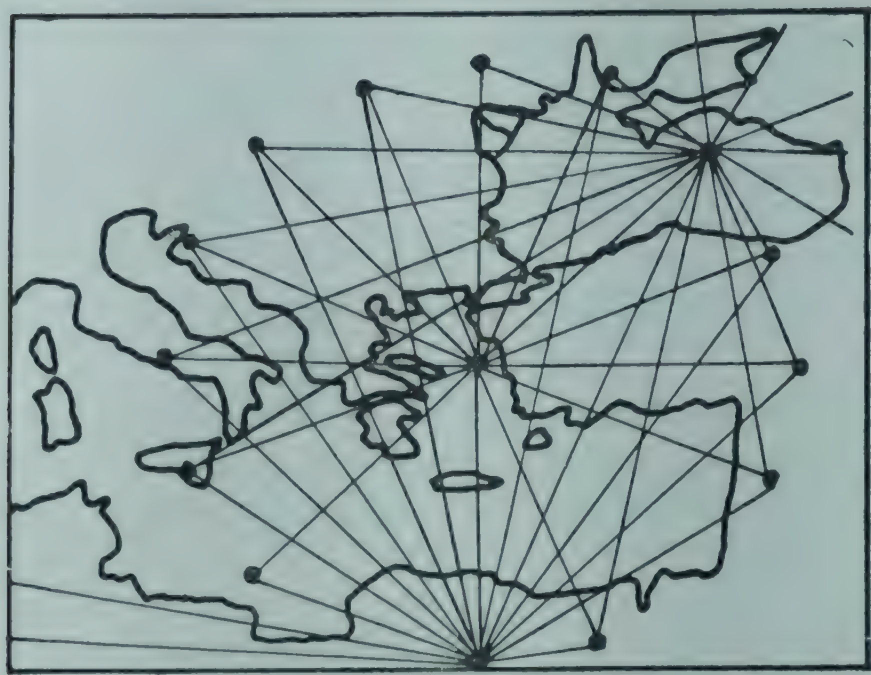


Figure 11: A sketch of a section of the portolan chart.

Figure 12: Outline of the Catalan world map.

The sources of the Catalan Atlas were many but the following four were most important: (1) the circular world maps of the classical and medieval times (2) Portolan charts showing the outlines of the Mediterranean sea, Black sea and the European coasts, (3) narratives of the 13th and 14th century travellers such as Marco Polo, and (4) narratives and charts prepared by Arabs and available at Barcelona. It was for the first time that the whole of Asia had been shown in a map, although very inaccurately as compared to

Europe. The lakes, the rivers and the mountains together with important places were shown in accordance with the narratives of Marco Polo. Indian peninsula was emphasized and innumerable islands were shown in the Bay of Bengal and along the coasts of South-east and East Asia.

The importance of these maps lies not in how accurately they represented the world but in the diligence the cartographers applied in using the available data to present a world picture which was quite different from the accepted one. The cartographic approach was scientific in the sense that only those details were given for which evidence was available; and the speculative aspects were de-emphasized. This is evident from the fact that they did not show northern and southern regions of the world, nor did they show the southern part of Africa.

The subsequent cartographic work in Europe was influenced by Ptolemy's 'Geography' as its manuscripts were widely circulated in Western Europe during the opening decades of the fifteenth century. Moreover, the narratives of Nicolo Conti's travels were available after 1447. Perhaps on the basis of these and other sources an elliptical world map was prepared in 1457 at Genoa. In this map the Asian outline is Ptolemic but the details bear considerable influence of Conti. Great details of the south Asian islands are the characteristic features of this map. The Indian ocean is not shown as an inland sea. Another work of great cartographic significance was the world map of Fra Mauro, a monk of Murano, near Venice. He started from the usual practice of having Jerusalem in the centre of the map but tried to modify many of the concepts of Ptolemy. He doubted many other prevalent concepts and thus displayed a critical spirit in cartographic thinking. But at the same time he gave a distorted picture of many of the bays, peninsulas and islands in Asia and Africa.

Toward the close of the 15th century, Martin Behaim, a native of Nuremburg prepared a globe. It was 20 inches in diameter and showed equator, the two tropics and the arctic and Antarctic circles. The equator was divided into 360 degree; the 80° meridian to the west of Lisbon was also shown. The worst mistake that Behaim committed was to accept Ptolemy's longitudinal measurement of the old world (177°) and added 57° more to accommodate the eastern parts of China. This gave a total of 234°, the correct figure being 131°. This being so, the distance between European and Chinese shores had to be reduced from 229° to 126° longitude for the total could not be more than 360°. Another map of importance was Henricus Martellus' world map of 1489. This was also based on Ptolemy's map (fig. 13).

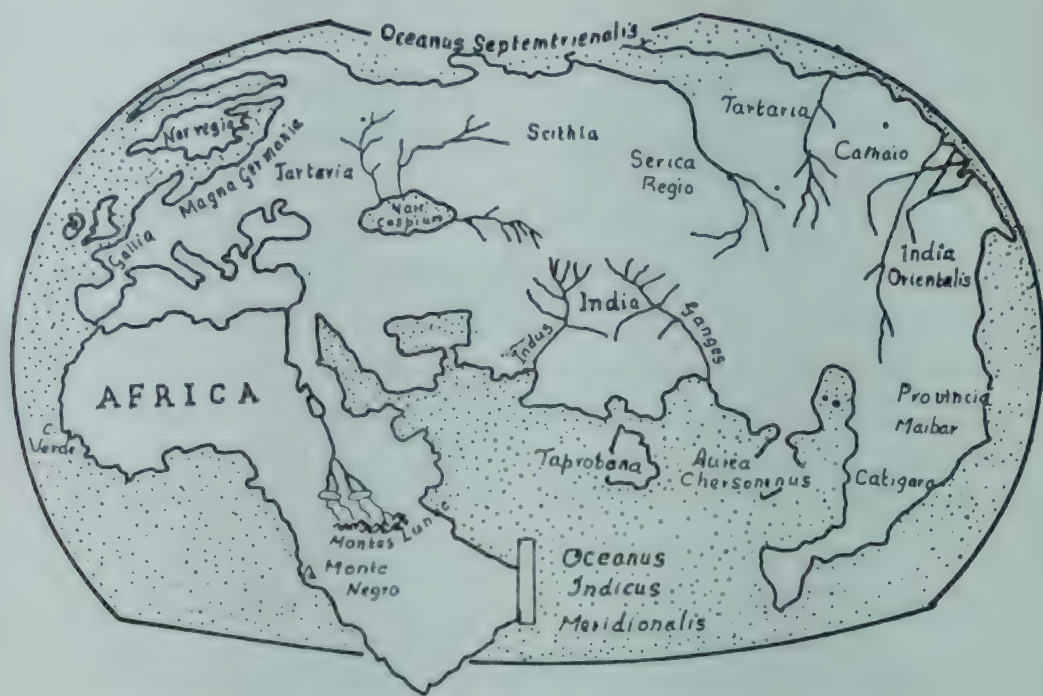


Figure 13 : Outline of the World Map of Henrieus Martellus.

Because of the increasing use of and reliance on Ptolemy's concepts by the cartographers of this period, attempts were afoot to multiply the copy of 'Geography'. The first printed edition of the book, without maps, appeared in 1447 and two years later Bologna edition came out with maps. Again in 1478 Rome edition of the books was also published. The maps of the Rome edition were engraved on copper. Soon, other editions also came out so that by 1482 four editions with maps had appeared, three from Italy and one from Germany. The height of Ptolemy's influence on cartography was reached with the publication of Geography at Strasbourg in 1513. The maps were wood-cut.

The publication of Ptolemy's Geograpy had two important influences on contemporary cartography. One was the extensive use of his ideas and the other the development of printing processes. Perhaps the latter aspect is as important as the former, for it heralded the multiplication of maps by cheap processes. The cheap edition of this book made the use of maps more common. It also enabled the people to judge the accuracy of Ptolemy's Geography against the data supplied by discoveries of Diaz, Columbus, Vasco-da-Gama, Cabral, Alfonso-d' Albuquerque and Magellan. One of the important contributions of these voyages was the method of finding out the latitudes with the help of the pole star and the mid-day sun.

EARLY MODERN PERIOD
(1500 TO 1800 A.D.)

By the first decade of the 16th century Ptolemy's maps were in good circulation and their accuracy was being increasingly questioned against the data supplied by the seamen who visited different parts of the old world. Thus the great discoveries during the decades of the late 15th and early 16th centuries contributed considerably to the revival of interest in cartography. During this short period a number of charts must have been prepared but only a few of them survive. Henricus Martellus' world map made in 1489 is an important contribution of this decade. Albert Cantino, a Portuguese prepared Cantino chart around 1500. Another map of significance is the King-Hamy chart of 1502. All these maps had considerably improved the outlines of Asia and Africa. It can, rather, be said that Cantino chart had entirely disproved many of the Ptolemy's concepts and speculated the existence of the Pacific ocean. Some regional charts were also published during the first decade of the 16th century.

Pedro and Jorge Reinel were the two official cartographers in the Portuguese court. Pedro made a chart of the Indian Ocean in 1518, and Jorge made a world map for Magellan's use. The fact that Maluccas, the chief source of spice lay near the Spanish-Portuguese demarcation line in the eastern hemisphere had a stimulating effect upon the study of cosmology and cartography of the region. In the western hemisphere this line of demarcation was 46° 37′ W and in the Eastern hemisphere 133° 23′E. Maluccas are at 127° 30′ E. The Portuguese part lay west of 133° 23′ E longitude.

The earliest among the Portuguese charts of this area which have survived dates from about 1510. In this chart areas west of Malaya are shown quite accurately but those east of it are misplaced latitudinally. Further improvements were made in Ribero's chart published in 1529 which included the whole circuit of the globe between the polar circles with the east Indian archipelago appearing in both the western and eastern margins. But even in this map the eastward extension of Asia continued to be exaggerated by about 20°. He placed Maluccas $7\frac{1}{2}$° within the Spanish sphere.

The Portuguese chart makers were famous all over the Western world. Leading cartographers were Pedro Reinel and his son Jorge Reinel, Lope Homem and his son Diogo Ribeiro, Fernao Vaz Dourado and Luis Teixeira. Most of the maps and charts were done at Casada India at Lisbon. Spain had its Casa de la Contracacion de las Indians at Seville for the same purpose. Among the important cartographers of this centre were Nuno Garcia de Toreno, Ribeiro and Alonso de Santa Cruz.

The other centres of mapping in Europe were in Rhineland, Netherlands, Germany, Switzerland and France. By 1500 the real centre of cartographic activity had shifted from Italy to the Iberian peninsula and Netherlands. Martin Waldseemuller who worked at St. Die in Vosges was the first to use the name America in his world map prepared in 1507 (fig. 14). The Netherlands

Figure 14: Outline of the world map of Martin Waldseemuller.

school of cartography was headed by Gemma Frisius of Louvain (1508–55). Gerhard Mercator was one of his pupils.

By 1525 the German and Netherland geographers and cartographers had devised geometrical methods of survey with more precise instruments for observation of angles. The famous geographer and cartographer Sebastian Munster, while at Heidelberg University, wanted his friends to survey an area within a radius of 6 to 8 miles of the town. He suggested the use of compass for this purpose. The method of elementary triangulation was first described by Gemma Frisius in his Cosmographia published in 1533. He suggested the fixing of positions of the objects by intersecting rays. Gradually the foundations for plane tabling were laid by Philip Apian and these methods were in full use by 1570.

With the progress of exploration, improved methods of surveying, and growing demand for topographical maps by travellers. statesmen, merchants and antiquarians, numerous maps of varying sizes and coverage flowed from the presses as the 16th century advanced. The Waldseemuller, Munster, and Lafreri (Italioa) atlasses were designed to meet this demand. But it was left to the Flemish cartographers, Ortelius and Mercator to serve in a practical way the public demand for an up-to-date and comprehensive atlas.

Gerhard Mercator was born at Rupelmonde in Flanders in 1512. He was a pupil of Gemma at the University of Louvain. His principal achievements were his globe of 1541 and his celebrated world map of 1569; his large map of Europe of 1554, his edition of Ptolemy, 1578 and his atlas of 1594 which was published posthumously. In his maps Mercator showed lines of constant bearing

by straight lines. This could not be done on maps having poleward converging meridians. He, therefore, arranged the meridians and the parallels as straight lines. To compensate for the increase in the east-west distances caused by straight line meridians (for meridians do converge polewards) he increased the distances between parallels proportionately. Thus area was distorted in his map but the directions and the shape were maintained (fig. 15).

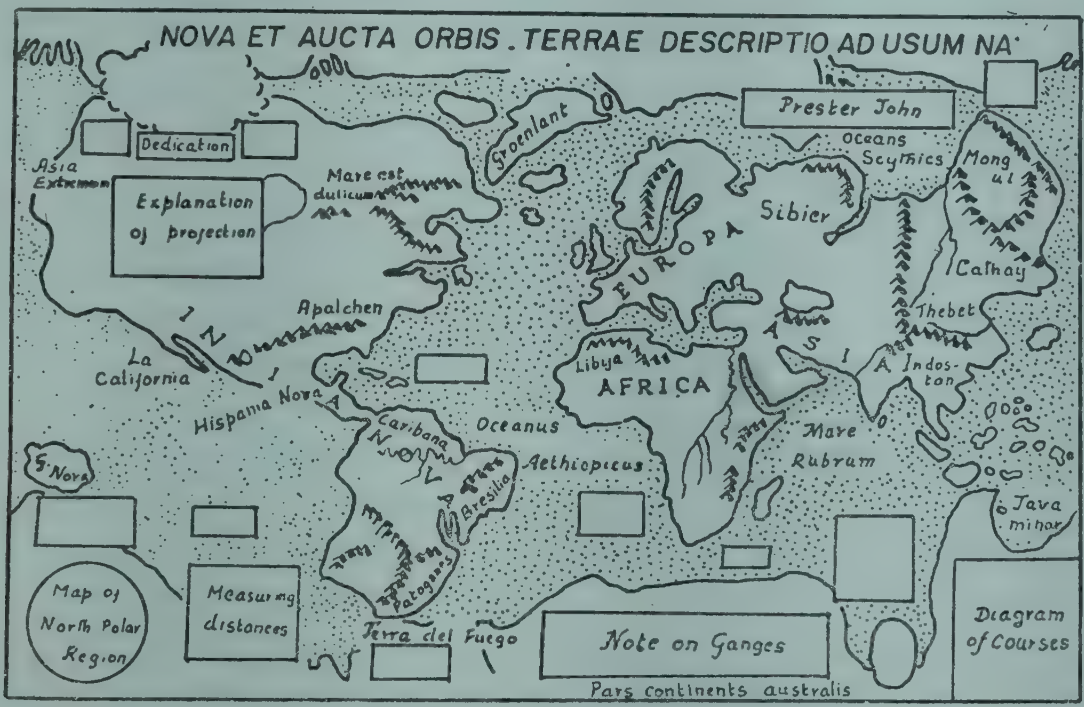


Figure 15: Outline of the world map of Gerhard Mercator.

Mercator's world map is conspicuious not only in respect of using a projection which gave correct shape and bearings but also in the sense that it gave a new conception of the world—a conception which was different from that of Ptolemy.

He showed three major land-masses one including Asia, Europe and Africa, the other, North and South Americas (erroneously called India Nova) and third, the continent of Australia. The last of the three landmasses was the result of the Greek conception of the existence of another continent as a counterpart of the inhabited world; some vague idea about Australia, and the existence of Terra del Fuegn, reported by Magellan, strengthened this belief.

During the later part of the 16th and the 17th centuries further data about Australia, North America, China and other parts of the world were gathered. In the meantime survey and other observational methods were improved with the development of telescope, logarithmic tables, pendulum clock and level. In 1671 Paris observatory was established and latitudes and

longitudes of an ever increasing number of places were recorded under the auspices of the Royal French Academy of Sciences. The academy also took up the preparation of detailed maps of France.

A remarkable contribution to cartography was made by the four generations of the Cassini family. Jean Dominique used the movement of Jupiter's satellite to calculate the longitude of a place. It was a definite improvement over the one based on lunar eclipses. The second Cassini, Jacques prescribed complete triangulation survey of France based on Paris meridian. His son Cassini de Thury almost completed the work in 1784. The Cassini map when complete comprised of 182 sheets (88×55.5 cm.).Delisle published general map of world between 1724–45. In these maps the longitudinal extent of North America was too large. The regional maps of D'Anville had the same deficiencies as the source of information was the same. Cassinis were followed by a succession of competent French cartographers. Important among them are Guillaume Delisle (1675–26), J. B. Bourguignon (1697–1782) and D'Anville.

D'Anville's work was carried on by his son-in-law, Phillippe Buache who developed better ways of representing relief by way of giving different symbols for mountains and hills and by shading the escarpments and valleys. Hans Konrad Gyger (1599–1674), a Swiss cartographer attempted to show the land surface as seen from above and thus he produced remarkable plastic effect by shading the lower portions and leaving the higher ones unshaded. During the 18th century J. G. Lehman developed the principles of hachuring. The system of showing relief by contours were also in use. The land contours were first used by Milet de Murcan in 1749 and the submarine contours by Phillippe Buache in 1737.

The earliest British map showing spot heights was Christopher Packe's Physico-chorographical chart of Kent. It was published in 1743. A further step in emphasizing the third dimension was taken when the colouring of areas between successive contours by a given scale of tints was adopted in Stieler's Hand atlas published in 1820. The advances made in the field of mathematics and astronomy during the eighteenth century helped the development of improved survey and measuring instruments. The quadrant was improved by John Hadley who added reflecting mirrors and vernier scale to it. Chronometer was develophd by John Harrison in 1772. Theodolite (in its essentials) was also developed during this period. It was first employed in triangulation survey of England and France in 1787, and later in the Ordnance Surveys of Britain and India. The British were also active both in America and India. Rennell, the Surveyor General of india, published his map of Hindustan in 1779. The first

edition of his Bengal Atlas with maps on a scale of 5 miles to 1 inch was published in London in 1779, two years after Rennell's retirement from the Survey of India. Gradually London became the leading centre of cartographic production. Perhaps the most important of British cartographer of this period was Arrowsmith who prepared a chart in nine sheets of the Pacific Ocean in 1778. The dimensions of this chart when mounted are over 6′ × 7′ 6″.

RECENT PERIOD
(1800 A. D. ONWARDS)

The chief characteristics of this period are the (1) the conducting of national surveys ; (2) mass production and use of a variety of maps ; (3) ever increasing influence of science and technology ; and (4) international co-operation.

During this period a number of countries established national survey institutions which carried out the great national surveys of the nineteenth century. These surveys were largely based on methods used by the Cassinis. Gradually the survey instruments were improved enabling the surveyers to record observations more correctly. The errors resulting from such causes as refraction, curvature of the earth's surface and climatic changes were taken into account in recording observations. The systametic topographical surveys were carried out in seven stages : (1) determination of mean sea level to which all altitudes are to be referred ; (2) a preliminary plane table reconnaissance to determine suitable points for triangulation ; (3) determination of initial latitude, longitude and azimuth ; (4) measurement of the baseline ; (5) triangulation with the help of theodolite ; (6) calculation of the triangulation and heights, and the transference of the trignometrical points to the sheets issued to the plane tabler ; and (7) filling in of the details by the plane tabler.

The accuracy and efficiency in surveying were considerably increased with the use of theodolite, wireless and other mechanical aids. With the introduction of camera in 1920 it was possible to use the aircrafts also for surveying. The aerial camera advanced the mapping of the visible face of the earth at a speed and with a fullness of detail never before obtained. When carreid aloft in airplane it became possible to photograph even those areas which were invisible to the earth bound observers. The problems of air surveys are related to obtaining suitable photographs, providing the necessary ground control for the framework of the map, and filling in the details from the photographs,

The development of several electronic devices has further revolutionized the cartographic processes. Almost all the countries of the world have establishments charged with surveying of land. Those which do not have, rely on other

countries for this purpose. In the United Kingdom, the Ordnance Survey of Great Britain was officially established in 1791. In France the Institute Geographique National is responsible for National Surveys. The U. S. Geological Survey is now the chief agency for topographical mapping in the United States and in India it is the Survey of India which carries out National Survey programmes. All these organizations produce 1/1 million maps in addition to several other series of larger scale maps.

The camera has revolutionized the cartographic processes not only by enabling the surveyers in getting quick and better results but also by assisting the cartographers in their laboratory where maps are designed and developed. Special cameras have been developed which help cartographers in compilation, drafting and reproduction of maps.

The mass production and use of maps of various types is another distinguishing feature of this period. The types of maps produced, the methods and techniques of representation of the qualitative as well as the quantitative data to suit the varying needs of the map users and the construction of thematic maps to meet the needs of specialized groups are some of the special developments of this period.

The use of maps as tools for research was demonstrated by such early geographers like Alexander Von Humboldt and Karl Ritter. Humboldt, in particular, showed that cartographically a great variety of facts could be represented in an orderly and readily intelligible manner. Many of his students like Adolf Stieler who published his Hand-Atlas in 1817 demonstrated the use of cartographic techniques in portraying complex details of the earth's surface. Later Physikalischer Atlas was issued by Heinrich Barghaus in 1838. Its next edition (1852) contained several thematic maps. At the same time John Bartholomews (father and son) in England published several atlases. At present the Soviet Union is engaged in producing a series of atlases of the world and of differnt regions of the U.S.S.R. Some of these atlases contain extra-ordinarily good maps.

A later development in atlases, arising from general advance of geography, has been the publication of National Atlases. The first of this type was Royal Scottish Geographical Society's Atlas of Scotland published by J.G. Bartholomew in 1895. The Atlas of Finland was published in 1899, and Atlas of Canada, in 1906. Czechoslovakia, Germany and France also published National Atlases. The French Atlas had maps on 1 : 1,000,000 scale. Atlas of American Agriculture prepared by A. E. Baker was published in 1936. The Soviet Atlas of the world was published in two volumes in 1937 and 1939. India published its first National Atlas in 1957.

An outstanding feature of modern cartography is the ease with which many of the mapping processes can be accomplished. Today we have materials on which details can be scribed and negatives or positives obtained without going through the photographic processes. The printing processes are also revolutionised so that one can have presses with built-in process of multi-colour printing. Drawing instruments have not only been improved but also multiplied in number.

Cartography as a science got a further fillip by its international recognition. The United Nations has a cartographic department and since 1961 an International Cartographic Association is also functioning. Under the auspices of the cartographic department of the UNO 1:1 m series of International Map of the World (IMW) are being produced. In addition to this, the International Council of Aeronautical Organisations (ICAO) is engaged in preparing ICAO world æronautical charts on 1:2 million scale.

With these developments, the problems of cartographic portrayal have, however, not decreased. As the variety in the availability and type of data increases and as new demands emerge from the increasing number of map users, new and better methods have to be evolved. There are thus greater opportunities in store for cartographers as professionals. There is now a greater need to attract people to the profession who will be devoted to further improving the techniques of cartographic representation.

CHAPTER IV

EARTH AS A CARTOGRAPHIC PROBLEM

The earth is a member of the solar system and hence its shape, size and movements are directly governed by its relations with the sun and other planets. The sun, as we know, is the prime source of energy and light for the earth. It is also the reference object for keeping the time. The moon which is the satellite of the earth, produces tides in the oceans. Many other planets and the stars also act as reference points for the determination of one's position on the surface of the earth.

Presently, we are well aware that the sun is the centre around which all of its planets, including the earth revolve. In other words, we believe in what the scientists call the helio-centric (sun centered) model of the solar system (fig. 16). This model is supposed to have been first mentioned in De Revolutionikus Orbium Coelestium written by Niklas Koppernigk (Copernicus) in 1543. Before this, people believed in a geo-centric model of the solar system. In this system the earth was considered to be the center around which other planets and stars revolved (fig. 16). The heliocentric theory was further refined by Newton and Kepler who said that the orbits of the planets are slightly elliptical and that the stars do not revolve round the sun.

The period required by a planet to revolve round the sun is called a planetary year. During the course of its revolution around the sun, the earth is 94.5 million miles from the sun in July and 91.5 million miles in January. In July it is said to be at aphelion (*ap* means away and *helios* means sun) and during January, at perihelion. The average distance from the earth to the sun is 93 million miles.

The earth revolves round the sun in a counter-clockwise direction. It completes one revolution in one sideral year which is a few minutes longer than the calender year. Similarly, the moon completes one revolution around

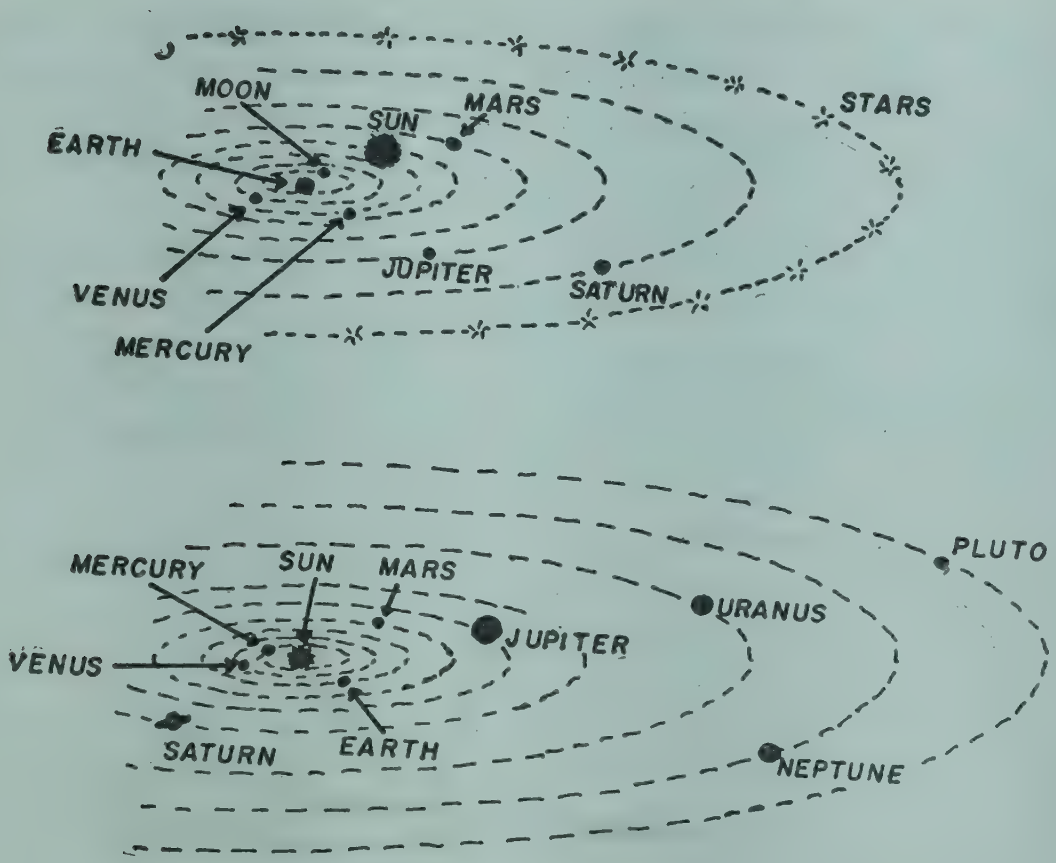


Figure 16 : Top : helio-centric model of the solar system.
Bottom : geo-centric model of the solar system.

the earth in one sideral month which is equal to 27.3 days. The earth itself rotates on its own axis in one sideral day which is equal to 23 hours, 56 minutes, and 4.09 seconds. As a complete rotation of the earth on its axis is equivalent to 360 degrees, the earth rotates 15 degrees every hour. Thus the local apparent solar time at a given time changes one hour for every 15 degrees of longitude. It decreases as one moves to the east. By an international agreement, it begins at the International Date Line which roughly follows the 180 degree longitude. One gains a day when crossing this line from west to east, but loses a day when crossing it from east to west. The Greenwich civil time is considered as the base for finding out the time of other places. The Greenwich Meridian is the zero degree meridian and the time on both sides of this meridian differs from its time by one hour for every 15 degrees of longitude.

SHAPE OF THE EARTH

The early thoughts about the shape of the earth ranged from the flat disc advocated by Homer to the sphere suggested by Pythogorus. Pythogorus was a mathematician and to him the most perfect figure was a sphere. He reasoned that God will create only a perfect figure and, therefore, the earth must be

spherical in shape. The Pythagorian idea was apparently based on the phases of the moon. About two hundred years later, Aristotle was led to the same conclusion. In the third century B. C. Eratosthenes demonstrated that the earth is spherical by measuring the angle at which the rays of the sun fell at two points located on the same longitude but on different latitudes.

Eratosthenes had observed that on the day of the summer solstice, the mid-day sun rays were directed to the bottom of a well in the town of Syene (now Aswan). At the same time, he observed that the sun was not directly overhead at Alexandria. It rather cast a shadow with the vertical equal to 1/50th of a circle i.e. 7° 12′ (figure 17). On the basis of the known facts that

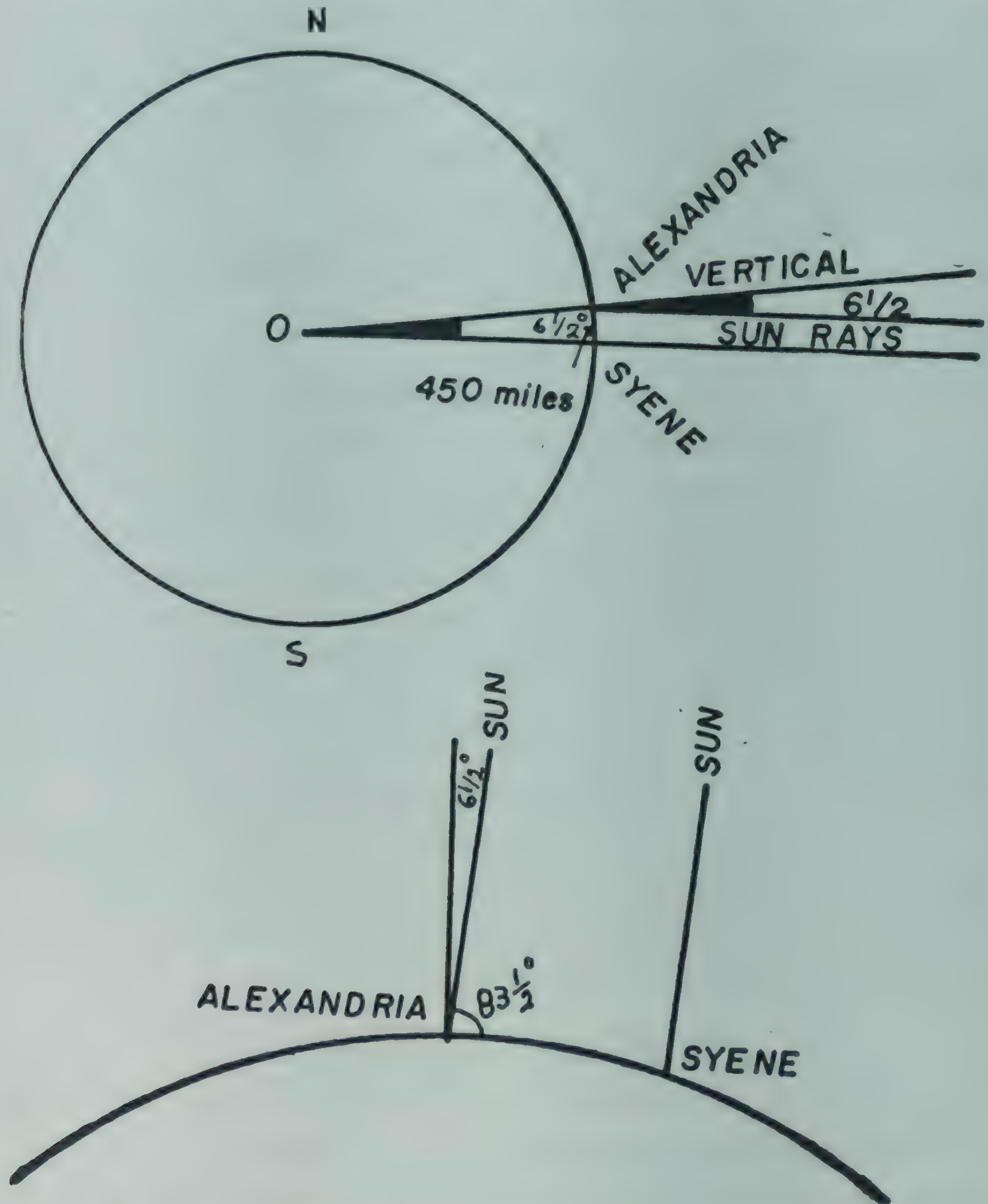


Figure 17 : Eratosthenese way of determining the circumference of the earth.

(1) Syene was situated on the tropic of cancer because the mid-day Sun was overhead on the day of summer solstice (2) the linear distance between Alexandria and Syene was 500 miles and (3) Alexandria and Syene lay on a direct north-south line, he concluded that the circumference of the earth must be 50×500 miles $= 25{,}000$ miles. The accuracy of the result is remarkable because the presently accepted value of the circumference of the earth at the equator is 24,899 miles. It is even more remarkable that such an accuracy was obtained eventhough the facts which were made as the bases for the calculations were not correct. As we know Syene is not at the tropic of cancer, it is about 37 miles north of it; the distance between Alexandria and Syene is not 500 miles, it is only 453 miles, and Syene and Alexandria are not on the same longitude. The latitudinal difference between the two places is not $7° 12'$. It is only $7° 5'$.

The next significant advance in geodesy came in 1617 when Snell calculated the circumference of the earth from astronomical measurements. Later in 1671 Richer in French Guiana discovered that gravity was weaker near the equator than on the higher latitudes. After fifteen years, in 1786, Issac Newton gave the correct description of the shape of the earth as being an oblate spheroid with its polar radius shorter than the equatorial radius. The theoretical proof of the spherical shape was given by Clairaut in 1743. Since then only minor changes have been made in Clairaut's model. The recent satellite measurements have resulted in two small modifications in the shape of the earth. One is the discovery that the southern hemisphere has a slightly larger circumference than the corresponding latitudes in the northern hemisphere, making the earth some what pear-shaped. The other is that the equatorial cross-section of the earth is not an exact circle; it is slightly elliptical and tri-axial.

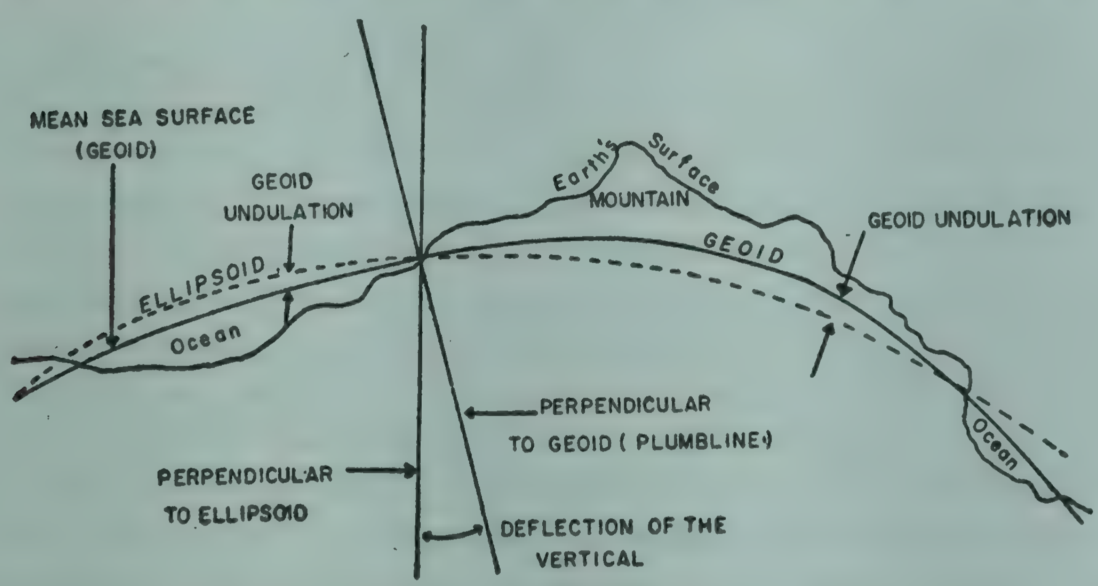


Figure 18 : Difference between an Ellipsoid and a Geoid.

Since the earth is flattened slightly at the poles and bulged somewhat at the equator, the geometrical shape used in geodetic computations is an ellipsoid of revolution (figure 18). This is a figure which one would obtain by spinning an oval disc on its flat side or by rotating an oblate ellipse on its north-south axis.

The following ellipsoids are currently used in different parts of the world :

Name of the ellipsoid	Year	Equatorial radius	Flattening	Where used
Everest	1830	6,377,276	1/300	India
Airy	1830	6,376,542	1/299	Great Britain
Bessel	1841	6,377,397	1/299	Japan
Clarke	1866	6,378,206	1/295	North America
Clarke	1880	6,378,249	1/293	France/Africa
International	1924	6,378,388	1/297	Europe
Krassowsky	1940	6,378,249	1/298	U. S. S. R.

The ellipsoid of revolution differs from reference surface called geoid (fig. 18). Geoid represents a level surface i. e. one that is perpendicular to the direction of the force of gravity. To visulize the geoid, imagine the surface of the earth to be completely covered with water. The surface of this endless sea will correspond to the geoid. Because of the irregularities in the distribution of the earth's mass, this surface slightly departs from the reference spheroid or the ellipsoid of the revolution.

GRAVITY OF THE EARTH

The concept of gravity is one of the fundamental cornerstones of geophysics. In cartography, gravity is of special significance mainly because it helps us in determining the shape of the earth. The idea that the earth attracts everything towards its centre had been prevalent even in ancient times. In India the concept of 'Gurutwakarshan' was developed during the Vedic and Puranik times. In Greece Aristotle believed that the speed of a falling body depended on its mass. Early in the seventeenth century Galileo refuted this theory and proved that all bodies, irrespective of their masses, fall with the same constant acceleration. The acceleration of a body is the rate at which its velocity changes with time. Half a century later, Newton formulated the law of gravitation and thus explained the rotation of the planets and their satellites. He calculated the magnitude of the gravitational pull of the earth being proportional to the mass of the body falling on the earth multiplied by

the mass of the earth (a constant) and inversely proportional to the square of the distance between the centre of the mass of the body and the centre of the mass of the earth.

It is the force of gravity which is largely responsible for the present shape of the earth. To understand this let us imagine a soft plastic sphere rotating about its axis. Because of the centrifugal force (inertia) the mass is pushed outward from the axis of rotation. As this force increases with distance from the axis of rotation,it is more effective at and near the equator. As a result, the sphere bulges outward around the equator and an oblate spheroid comes into being. That is the present shape of the earth (figure 19).

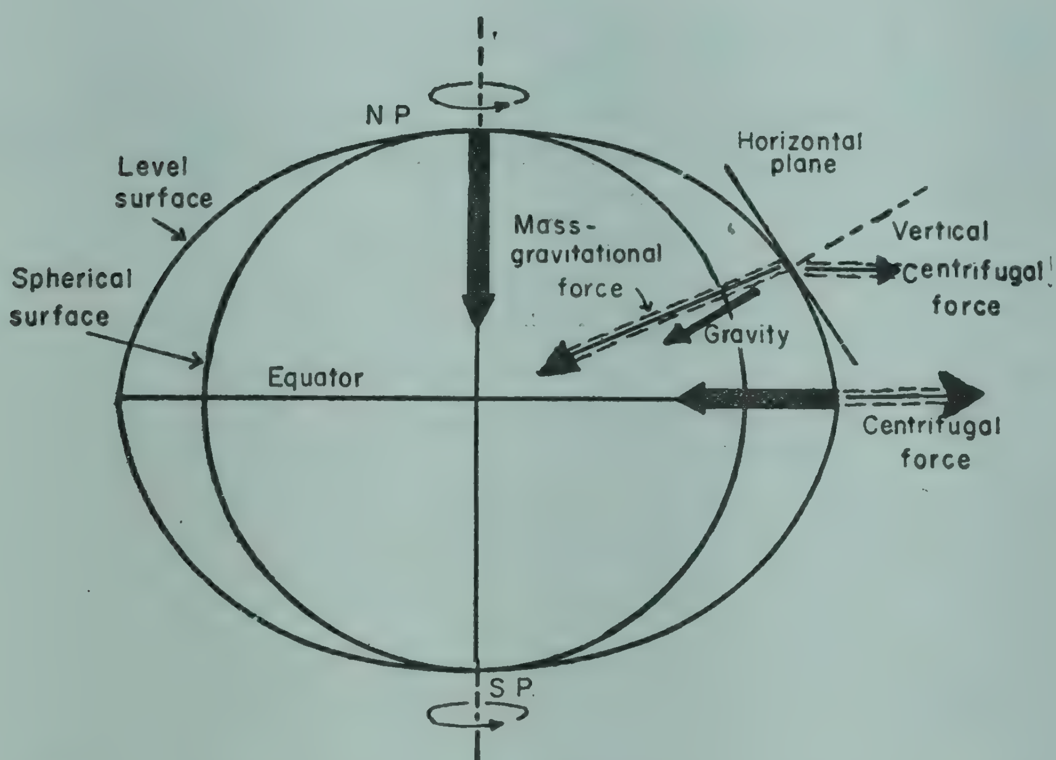


Figure 19 : Effects of the rotation of the earth and its gravity on its shape.

An object on the rotating earth is subject to outward-directed centrifugal force which increases from zero at the poles to a maximum at the equator. The gravitational force due to the earth's mass is directed toward the centre of the earth almost everywhere but the centrifugal force detracts it from the centre. The measured gravity of the earth is the result of the combination of mass gravitation and centrifugal force. Gravity is, therefore, weaker at the equator than at the poles. It is about 0.5 percent greater at the poles than at the equator.

DIMENSIONS OF THE EARTH

The International Union of Geodesy and Geophysics (IUGG) has accepted the following measurements of earth's radius :

Polar radius	6357 km
Equatorial radius	6378 km
Mean radius	6371 km

The surface area of the earth can be determined easily if we know the radius of the earth. Area of a sphere is 4 π times the square of its radius ($4 \pi r^2$). The area of the earth is about 197.26 million square miles. Its volume is about 260 billion cubic miles. The total mass of the earth as determined by the gravitational force is almost 5.98×10^{27} grams. When we divide the mass (5.98×10^{27} grams) by the volume (1.08×10^{27}cu.cm.) we get the average density of the earth (5.52 grams per cu.cm.) This is 5.52 times greater than the density of pure water.

One of the basic problems in cartography is to reduce the earth to a convenient size and to transfer the spherical shape of the earth on a plane surface.

CHAPTER V

SCALES AND THEIR FUNCTIONS

The size and shape of the earth discussed in the previous chapter create two basic problems for cartographers. One of them is how to shrink the earth down to usable map size and the second is how to pin the spherical earth down on a flat surface. This chapter is devoted to the logical resolution of the problem of reducing the earth to the usable map size.

Scale is the means which enables us to reduce the whole or a part of the earth to a size which is not only convenient and handy but also logical and scientific. A general definition of scale is that it is a ratio between the distance on a map and the corresponding distance on the earth. For example, if two points located 10 miles apart are shown 1 inch apart on a map, then the scale of the map is 1 inch to 10 miles. It must, however, be pointed out that the scale of a map does not show the ratio of actual distances between the corresponding points as almost all Cartography and Practical Geography books say. It is only the horizontal straight line distance that is taken into account. So if the airline distance between two points is 100 miles and the actual distance is 120 miles (as they are separated by very high mountains) we will take only 100 miles into account for the purpose of scale. (fig. 20).

So a scale represents a ratio $= \dfrac{\text{Map Distance}}{\text{Ground Distance}}$

If one unit of map distance is equal to 1000 units of ground distance, the scale of the map is :

$$\frac{\text{Map Distance}}{\text{Ground Distance}} = \frac{1}{1000} = 1 : 1{,}000 = \text{map scale}$$

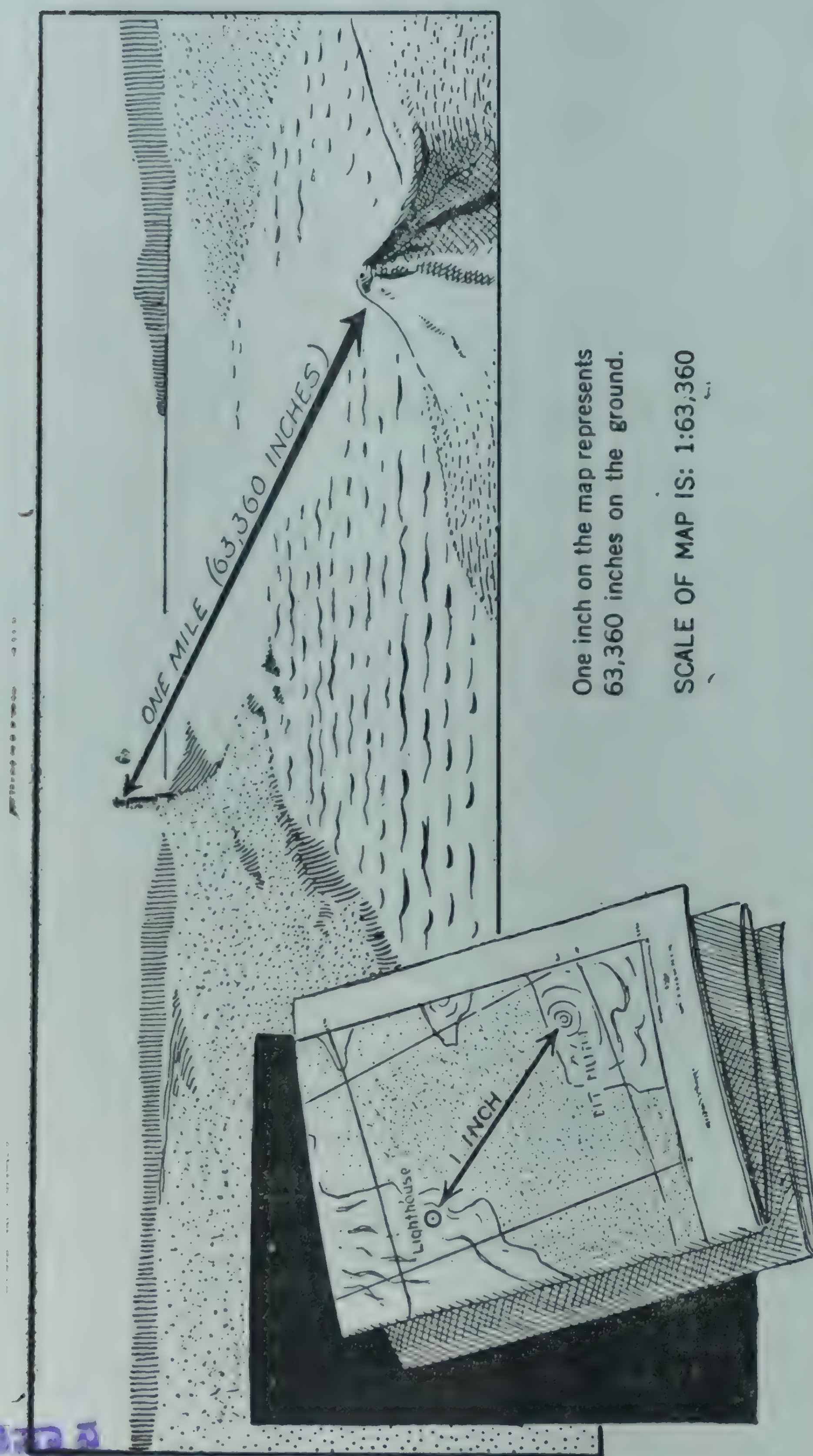


Figure 20: Scale is a means to reduce the size of the whole or part of the earth surface. (From Map Intelligence)

Similarly if 1 inch on a map represents 1 mile on the ground, the scale of the map is :

$$\frac{\text{Map Distance}}{\text{Ground Distance}} = \frac{1 \text{ inch}}{1 \text{ mile}} = \frac{1 \text{ inch}}{63{,}360 \text{ inches}} = 1 : 63{,}360$$

The above examples give a clear picture of how scales are the ratios between the distances on a map and on the ground. Ratios are also known as fractions. Consequently, scale ratio of map to earth is a representative fraction or RF.

$$RF = \frac{\text{Map Distance}}{\text{Ground Distance}}$$ (When both are shown in same units of measurement.)

Representative fraction is read and interpreted just like any common fraction and produces the same proportions. When the denominator is small each part represents a large piece of the whole. For example, it takes only two parts to make one whole in the fraction 1/2. As the denominator increases, it takes more parts or in other words, one part represents a smaller piece of the whole. Since map scales are generally expressed in comparatively small intervals of linear measurement, they show several thousand parts expressed in one part of unit. On a scale of 1 : 20,000, twenty thousand ground units would be compressed into one map unit.

Every good map must have a scale to tell its reader what to expect in the way of details as well as to help him estimate distances. Large scale means that specific features of the landscape such as individual buildings and intricate local patterns will be shown on a map covering a small area. As more area is covered by the same size map, exactness of delineation decreases and less details can be shown within the scope of each map unit. When a suggestive outline circle or dot, for example, replaces actual details, more earth area is covered in each map unit and the scale is either medium or small. Thus increasing the size of the denominator means making of each detail smaller and less exact.

Objects can be reduced only so far and then they must be eliminated because it becomes impossible for the human eye to see them. Important details to be retained on a map have, therefore, to be exaggerated. These are no longer drawn to scale. So we should not expect a map to give every detail to scale. What we should be sure of is, that all maps give areas covered by spatially distributed details to the scale shown in the map.

NOTATION OF SCALE

Representative Fraction (R. F.) :

We have already noted the meaning and significance of scales. We have also seen how they are representative fractions. So one method of giving scale

is to give the representative fraction (RF·). The numerator of the RF determines the unit of map distance while the denominator determines the amount of earth distance represented by each map unit.

Verbal notation :

Another way of expressing scale is to make a simple statement giving the number of map units as a fraction of the corresponding earth units. So instead of saying 1:63,360 we can say that one inch on the map represents one mile on the ground. To further shorten the expression we can say.

One inch to one mile, or

1 inch = 1 mile

Graphic Scale :

Still a third way of showing scale is by means of a bar graph. The bar scales are calibrated to express visual equivalents of the representative fraction or verbal scale. They can be used directly without the preliminary conversion needed in representative fraction. Further more, they are more convenient to use if a map is to be reduced or enlarged photographically since the graphic scale notation automatically conforms to the change in scale. Beginners often commit the mistake of using representative fraction or verbal scale on originals drawn for printing on a reduced scale. If such scales are not computed for the printed map, they will be incorrect.

For graphic scales, a horizontal line or a bar of appropriate length is drawn and divided into desired units. In figure 21 the two main divisions of the graphic scale are shown. The primary portion to the right of the zero is divided into multiples of the whole units such as 1, 2, 3 or 10, 20, 30. The extension to the left of zero is divided into fractional parts of a whole unit, such as furlongs. This is done to enable the map reader to measure distances in fractions also. If we want to measure full units we will begin with zero and use the right side or the primary scale. But if the distance we are trying to measure does not equal primary units, we will place the line to be measured with the right end on the last full unit that is applicable and read the remaining fraction on the extension to the left of zero.

When such specific uses of bar scales are made, we must be sure that the scale is applicable to all parts of the map· Certain projections invalidate the use of a single bar scale beyond a limited graticule point· For example, a single bar scale for Mercator's projection is constructed only for a given parallel of latitude. Poleward distortions of the projection produce highly erroneous measurements. In such cases multiple scales adopted to correct proportions along succeeding parallels are necessary for correct measurement.

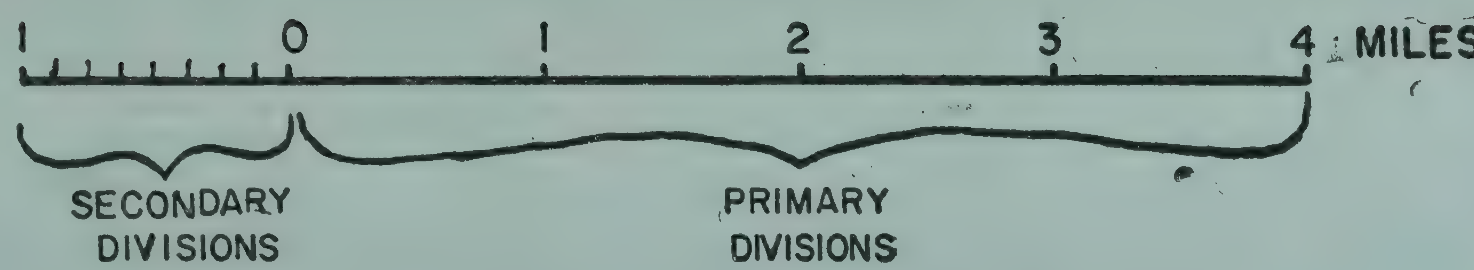


Figure 21 : Divisions of a graphical scale.

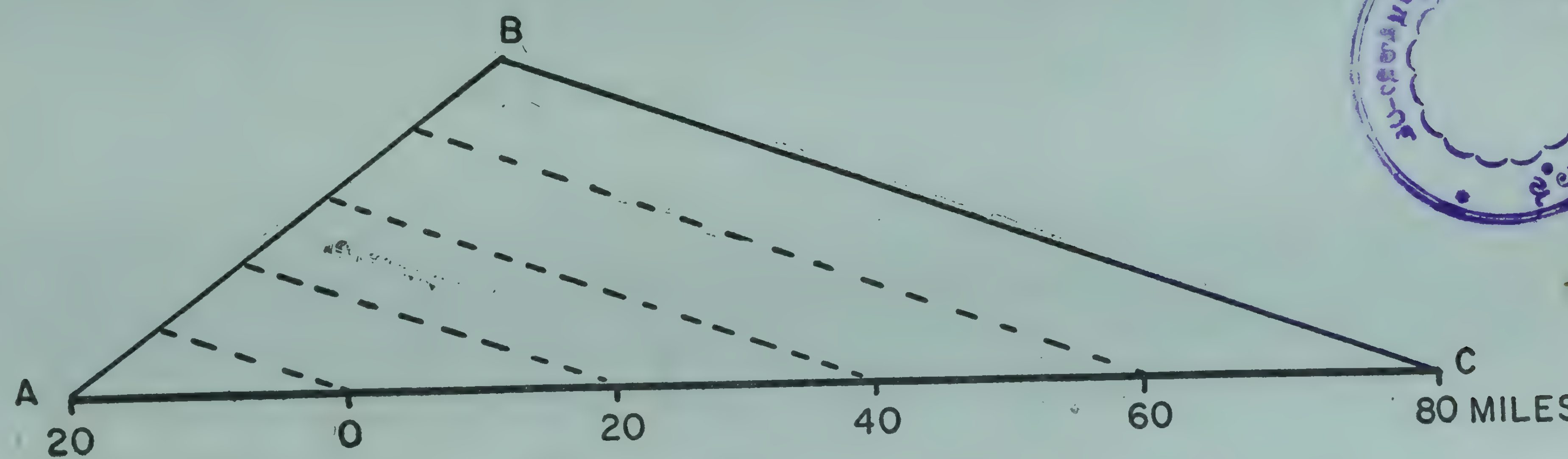


Figure 22 : Method of dividing a line into equal parts.

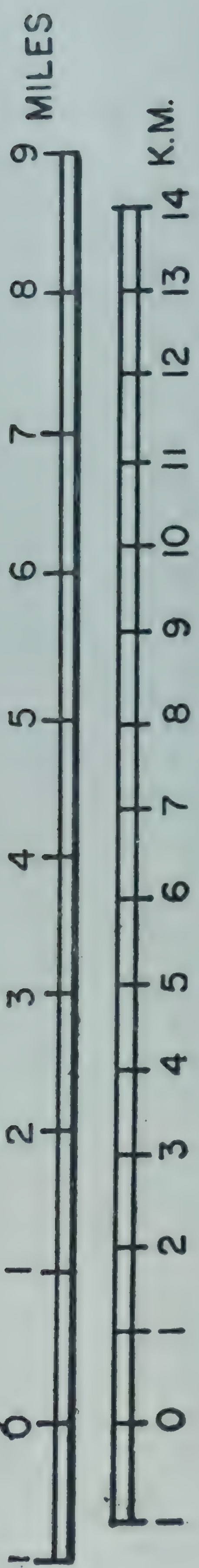


Figure 23 : A comparative scale showing Miles and Kilometers

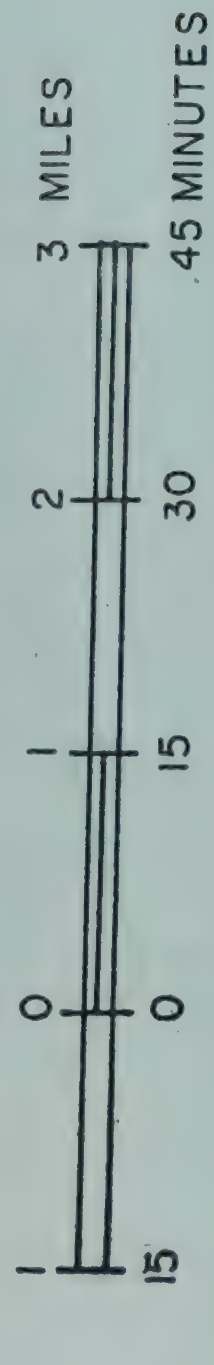


Figure 24 : Movement scale.

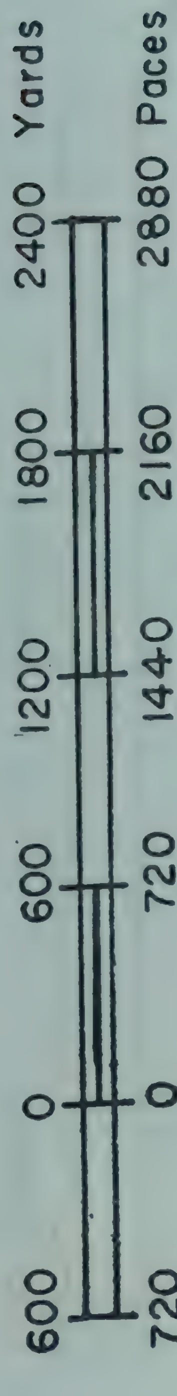


Figure 25 : Scale of yards and paces.

CONSTRUCTION OF GRAPHICAL SCALES

Before we discuss the technique of constructing a graphical scale, it would be desirable to note that these scales can be drawn to represent not only the absolute but also the comparative measurements. In addition to this they can be used to represent scales of cube roots and square roots. Rudiments of the methods of constructing each of these scales are given below.

Plane Scale :

Supposing that we are given a RF scale 1:63,360 and we are required to convert it into a bar scale. This scale suggests that one unit on the map represents 63,360 units on the ground. If we take inch as the unit of measurement, then one inch on the map represents one mile on the ground. To prepare a bar scale of miles, we should first select a convenient number of miles for representation. The convention is that a bar should not be longer than 6 inches or 15 cms and shorter than 3 inches or 7.5 cms. Of course, there are no rigid rules in this regard. Suppose that we have to prepare a scale for 5 miles. As 1 inch = 1 mile a base line of 5 inches is laid off and divided into five equal parts, each representing 1 mile, as shown in figure 21. We leave the first division on the left hand side for secondary divisions and start with zero at the end of the first inch from the left. In this case the line is to be divided into five equal parts and it so happens that it is exactly five inches long. But there may be cases where less or more than one inch might represent one mile. A line of say 6.34 inches may have to be divided into four or five equal parts. In such a case, the division will have to be made with the help of a diagonal line of conveniently divisible length, as we see in figure 22. Here AB is the diagonal line. It is divided into five equal parts because we have decided to divide the bar scale into five parts. B is then joined with the right hand edge of the bar. Parallel lines are drawn from each of the equally spaced points on line AB to the bar. Such lines divide the bar scale into as many equal parts as the line AB is divided.

Suppose the given RF is 1 : 1,000,000 and we have to construct a bar scale of miles. We will proceed as following :

As 1,000,000 units on the ground = 1 unit on the map
So, 1,000,000 inches on the ground = 1 inch on the map.
Therefore 63,360 inches (1 mile) on the ground

$$= \frac{1 \times 63,360}{1,000,000} = 0.0634'' \text{ on the map.}$$

We can now select a ground distance which gives a map distance of approximately 6″. Here 100 miles are selected which give 6.34″. Draw a bar of 6.34″ and divide it into five equal parts (figure 22).

At times two or more units of measuerment have to be shown graphically to give a comparative idea. In such cases we prepare two bars, one for each of the units. Suppose we have to show scales both in miles and kilometers and we are given a RF = 1 : 100,000. We have to select two different distances to be represented by the scale bars. The units should, however, be so selected that both the bars are approximately equal.

Mile Scale:

RF = 1 : 100,000 or 1 inch = 100,000 inches.

As 100.000 inches are represented by 1 inch,

$$63{,}360 \text{ inches (1 mile)} = \frac{1 \times 63{,}360}{100{,}000} = 0.634 \text{ inches}$$

So 10 miles will be represented by 6.34″

Kilometer Scale:

RF = 1 : 100,000 or 1 cm = 100,000 cm. = 1 Km.

So 15 Kilometers will be represented by 15 cm.

Both the mile and the kilometer scales are shown in fig. 23. These scales are so drawn that the zeros of the two bars coincide with each other.

Plane scales can also be made to show rates of movement. Suppose a contigent of army is moving at the rate of 4 miles an hour. We have to draw a time scale for a map of 1 inch to a mile. We will proceed as follows :

1 mile is represented by 1 inch

4 miles will be represented by 4 inches

Now 4 inches on the map will be covered by 1 hour or sixty minutes. We can draw a bar of 4 inches, divide the upper line of the bar into 4 parts to show miles and the lower part into 4 parts to show minutes (Fig. 24).

In certain cases we may have to measure distances by paces or revolutions of wheels. Such scales can also be given side by side with the scale of yards, meters etc.

Suppose the RF is 1 : 126,720 and the length of pace is 30″ (standard military pace) and we have to draw a scale of yards and paces.

For the yard scale :

RF is 1 : 126,720

$$\text{or } 1'' = 126{,}720'' = \frac{126{,}720}{36} = 3520 \text{ yards.}$$

Again 1″ represents 126,720″ or $\frac{126{,}720}{30} = 4224$ paces

Now 4224 paces will be represented by 3520 yds.

3600 paces ,, ,, by $\frac{3600 \times 3520}{4224} = 3000$ yards.

Let us take a 5 inche line as the base

Now 3520 yards are represented by 5″

3000 ,, ,, $= \frac{5 \times 3000}{3520} = 4.26''$

A line of 4.26″ is drawn and divided into 5 equal parts. Each division represents 600 yards and 720 paces (Fig. 25)

Similarly if we have a measurement by revolutions of a wheel, we can find the circumference of the wheel by the formula

$2\pi r$, where r = radius.

If we know the circumference of the wheel and the number of revolutions, we can calculate the distance covered by it. Both the distance and the revolutions can then be shown on the same scale. (Fig. 26)

Diagonal Scale :

A diagonal scale is drawn to give greater precision to measurement. It is very useful when we have to make the measurements to decimal points. Suppose we have to draw a scale of 4 inches to measure 2.56″. We draw a line AB of 4 inches and divide it into 4 equal parts (Fig. 27). From both A and B draw perpendiculars AC and BD measuring 1 inch each. Divide AC and BD into ten equal parts and draw lines parallel to AB. To get the secondary divisions of the scale, divide the top and bottom lines AA′ and CC′ into ten equal parts. Join zero of the bottom line with one of the top line, one of the bottom with the two of the top line, two of the bottom with the three of the top line, and so on. To measure 2.56 inches, place one leg of the divider at X and the other at Y. To measure 1.33 inches measure the distance MN.

The XY distance consists of Xa + ab + bY = 5/10 + 6/100 + 2 inches = 0.5 + 0.06 + 2 inches = 2.56 inches.

Vernier Scale :

It is a scale which enables us to estimate with greater accuracy a fraction of a division. It consists of a moving scale which slides along a primary scale. Suppose we have to construct a vernier with a least count of one hundredth of an inch, we follow the following procedure.

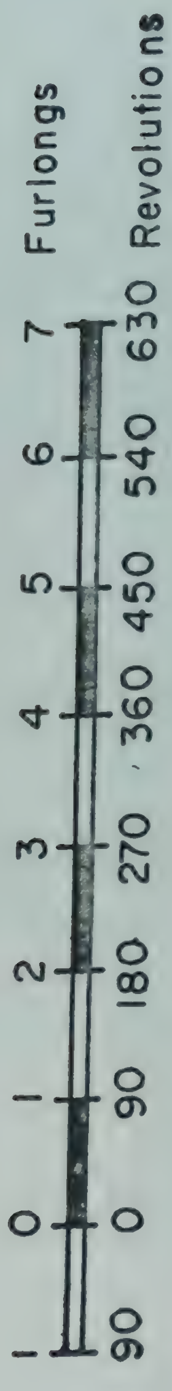


Figure 26 : Scale of furlongs and revolutions of a wheel.

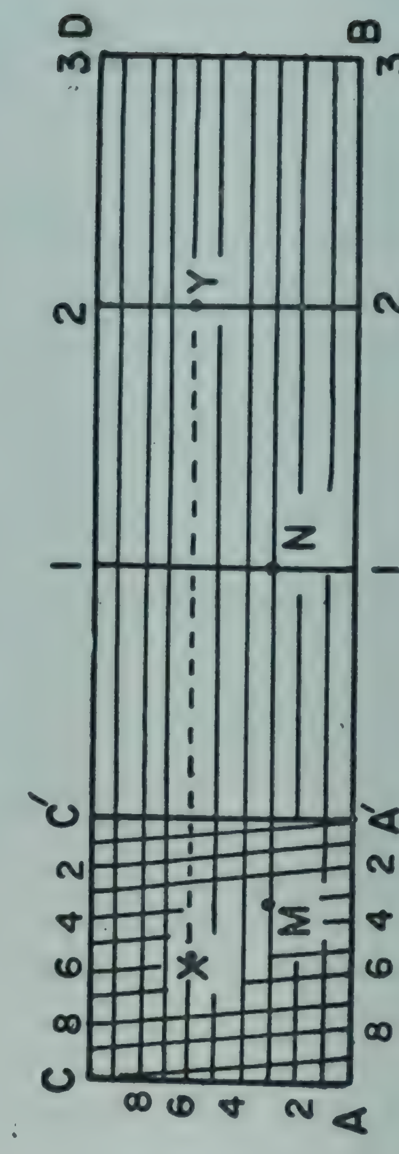


Figure 27 : A diagonal scale.

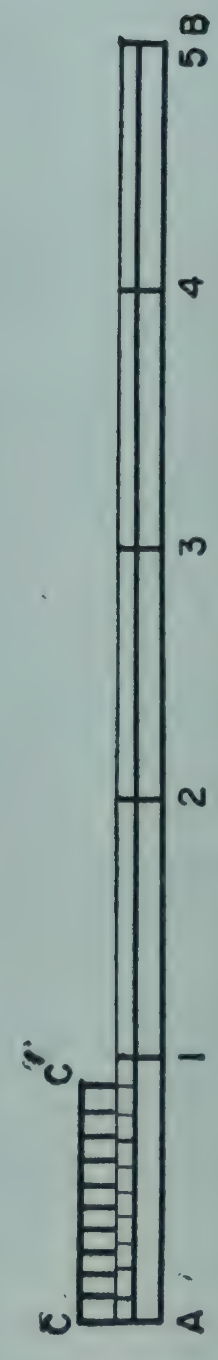


Figure 28 : A vernier scale for horizontal measurement.

Draw a line A B and divide it into inches and tenths of inches as shown in fig. 28. Now draw a vernier C C′ on A B equal to 9 small divisions of A B. Divide C C′ into 10 equal parts. Now, a small division of the vernier scale is 1/100″ shorter than a small division of the primary scale. (The vernier division is shorter by $\frac{1}{100}$ of an inch than a small division of the primary scale). In the fig. 28, zero of the vernier coincides with the zero of the primary scale and hence the first vernier division lags behind by 1/100″, the second by $\frac{2''}{100}$ and the third by $\frac{3''}{100}$ and the tenth by $\frac{10''}{100}$ or 1/10″ or 1 small division of a primary scale. To read 2.56″ slide the vernier, so that the zero of the vernier coincides with the 2.5″ mark on the primary scale. Now shift the vernier to the right, so that the 6th division of the vernier coincides with the primary scale graduation. The length between the zero of the vernier scale and the zero of the primary scale is 2.56″. Similarly we can have vernier scale showing degrees and minutes.

DETERMINING THE SCALE OF A MAP

To determine the scale of a map (if it is not given), first of all find out the ground distance between any two points shown on the map. Find out the map distance between the same points and compare the two. If the ground distance is two miles and the map distance is two inches, then 2 inches on the map represent 126,720 inches on the ground. Since the scale ratios are always expressed with one as the base, we divide both 2 and 126,720 by 2 to obtain the RF 1 : 63,360.

REDUCTION AND ENLARGEMENT OF SCALES

In the process of compiling maps cartographers are often required to reduce or enlarge maps. Reduction or enlargement involves change in the size. One simple way to illustrate what happens to the size of a map when it is reduced or enlarged is to fold a sheet of paper. Take a sheet of ordinary note book and assume it to be a map of a given scale. To show the same area reduced to 1/2 the original scale, fold the paper in half each way since any reduction is proportional in each dimension. Now we have one fourths of the paper area of the original, while the scale is 1/2 that of the original. Fold the paper once again in each direction to illustrate four times reduction which gives a paper having 1/16 the size of the original.

This paper folding can also be depicted mathematically. The ratio between the area of a map on one scale and its area to another scale is equal to

the square of the ratios between the scales of the original and enlarged maps.

Example 1: Reduce 1 : 10,000 to 1 : 50,000 scale.

$10{,}000 : 50{,}000 = \frac{10{,}000}{50{,}000}$ or 1/5 the original line or scale

and $(1/5)^2 = \frac{1}{25}$ of the area of the original.

Example 2: Enlarge 1 : 100,000 to 1 : 20,000

$100{,}000 : 20{,}000 = \frac{100{,}000}{20{,}000} = 5$ times the original line or scale and $(5)^2 = 25$ times the area of the original.

If we know the original scale of a map and want to find out the new scale of a reduced or enlarged version of it, we should use the principle of ratios.

Example 1: given scale 1 : 100,000 is to be enlarged 10 times

$\frac{1}{x} : \frac{1}{100{,}000}$ or $\frac{100{,}000}{x} = 10$ or $100{,}000 = 10x$

or $x = 10{,}000$

The enlarged scale is 1 : 10,000

Example 2: given scale 1 : 10,000 is to be reduced 5 times

$\frac{1}{10{,}000} : \frac{1}{x} = 5$ or $\frac{x}{10{,}000} = 5$ or $x = 5 \times 10{,}000 = 50{,}000$

The reduced scale is 1 : 50,000

G. SCALE

Haggett, Chorley and Stoddart have proposed a standard of geographical measurement which indicates the relative size of the area studied with the total area of the earth as the base. They call it G–Scale. G–scale of an area can be determined by the following general formula:

$$G = \log Ga/Ra$$

Where G = G–scale of the area studied

Ga = Earth's surface area

Ra = Area under investigation

The area can be measured in any of the several known units such as acres, hectares, square miles etc. Formula for computing G values from different conventional areal standards are given below :

Conventional Standard	*Formula*
Square miles	8.2941–log Ra ($mile^2$)
Square kilometers	8.7074–log Ra (Km^2)
Acres	11.1003–log Ra (ac)
Hectares	10.7074–log Ra (ha)

On the basis of this scale the following will be the G–scale for a few selected areas.

Earth —— G	
Asia (Excluding USSR)	G = 1.1
India	G = 2.2
Mysore state	G = 3.4
Mysore district	G = 4.2
Mysore taluk	G = 5.8
Mysore city	G = 6.9
University of Mysore campus	G = 8.30
Geography Department and its surroundings (10 acres)	G = 10·10

CHAPTER VI

DIRECTIONS AND THEIR FUNCTIONS

Direction has been defined as an imaginary straight line on the map or ground showing the angular position of various points with respect to a common base direction. The line pointing to the north is regarded as the zero direction or base direction line.

The two ends of the axis of the earth's rotation are known as north and south poles. These are also called geographical poles. The line that joins these two poles. is the zero direction line. Any line cutting this line at right angles is the east-west line. North, South, East and West are the four main directions. These are also called cardinal points. In between the cardinal points, one can have several intermediate directions as given in figure 29.

A map must have the base direction represented on it to enable the user to locate different features with respect to each other. Such a direction is often shown by an arrow pointing to the north. At times the base direction is not indicated on a map. This generally means that the top of the map represents the true north or that the longitudes are indicative of the north-south direction.

As we can see from figure 29, we can represent only a few intermediate directions by means of arrows. If we have to show a direction in between N E and E N E, we will be hard put to express it. It is for this reason that directions are often given in terms of angles. North is regarded as the angle of zero direction. All directions are expressed as angles, measured clockwise from north throughout the full range of the directional circle. These angles are called azimuths. In this system we have no problem with regard to expressing the angle between N E and E N E. All we have to do is to measure the angle between the zero direction line and the line pointing to the object whose direction is needed.

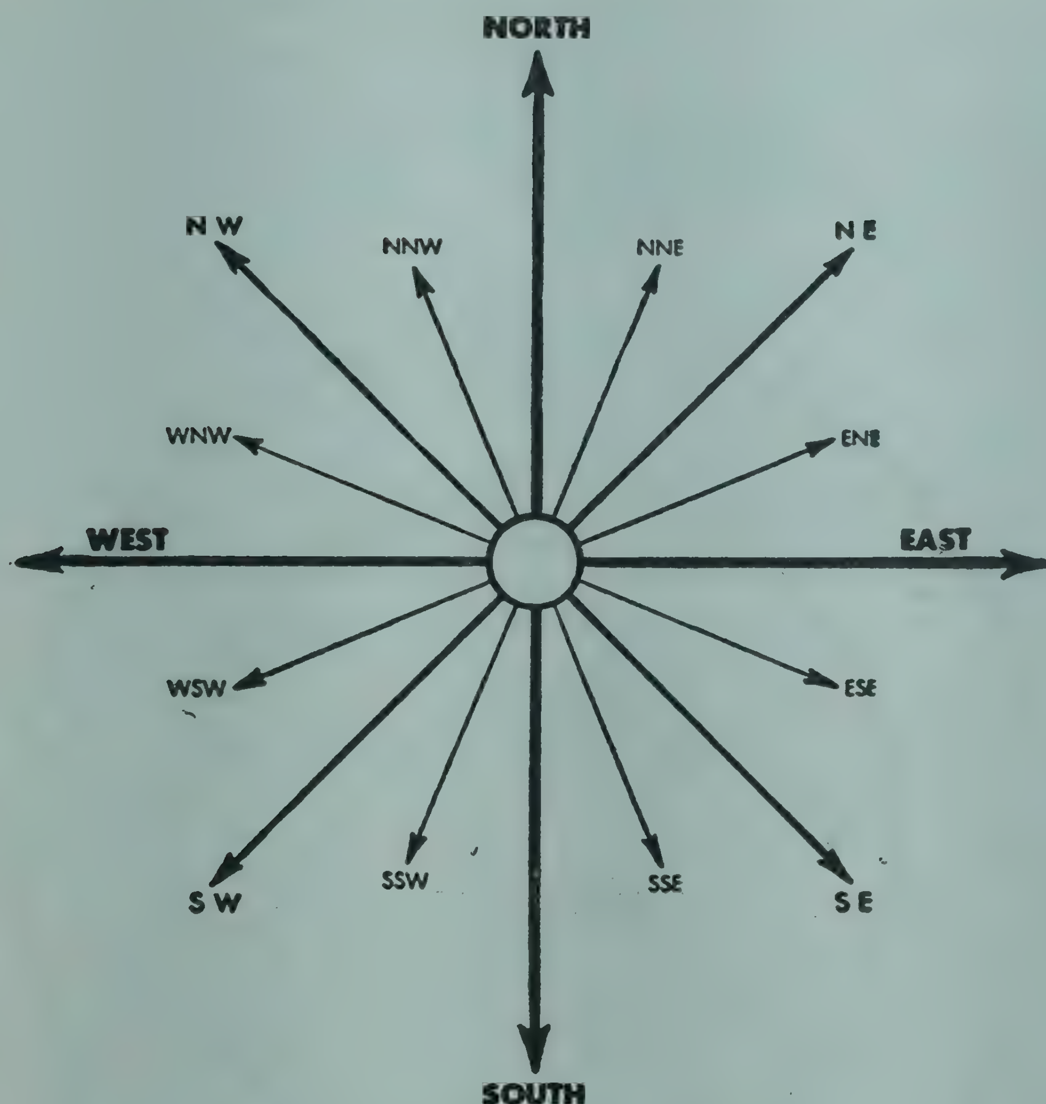


Figure 29: Cardinal and intermediate directions.

Like distances, directions can also be measured in any desired unit. Degree is by far the most commonly used unit of measurement. Mil and grad are the other units of measurement. The subdivisions of a degree are called minutes and those of a minute are called seconds. When a circle is equally divided into 360 angles each of the angles represents one degree. In the same way each degree is equally divided into 60 minutes, and each minute into 60 seconds. This plan establishes over one million seconds in a circle. With the help of these sub-divisions, it is possible to measure directions with utmost accuracy. For the sake of convenience, degrees, minutes and seconds are represented by conventional signs so that if we want to write 168 degrees, 56 minutes and 43 degrees, we will write 168° 56′ 43″.

A mil is the angle subtended by 1 yard across a distance of 1000 yards from the centre of a circle. It can also be expressed as an angle the tangent of

which is approximately .001. It is 1/6,400th part of the circumference of a circle, so that 90° = 1600 mils. Figure 30 shows the relationship between a mil and a degree. Mil is used more for military purposes because change of one mil in the direction of the tube of a weapon changes the centre of the impact of a round 1 yard at a range of 1000 yards, 2 yards at a range of 2000 yards and so on.

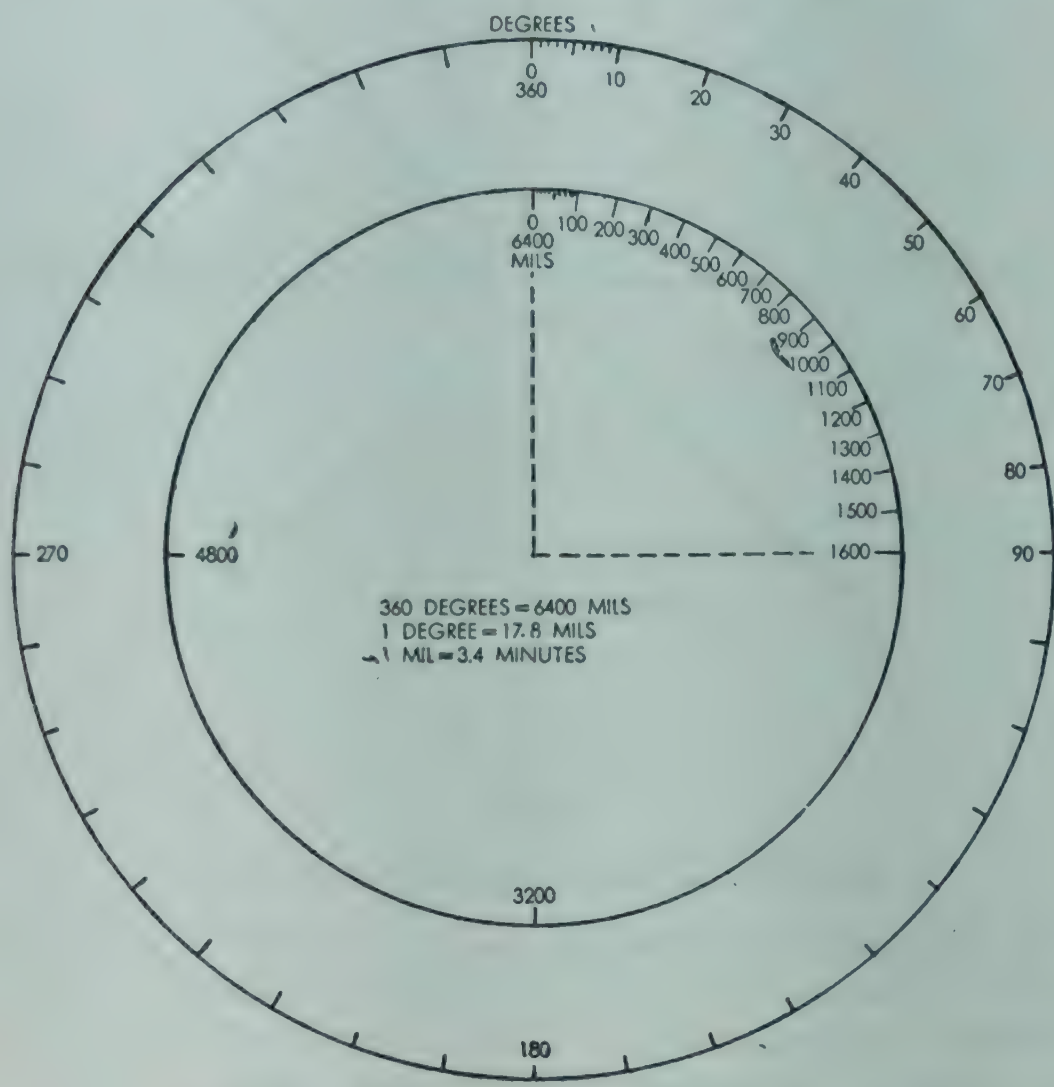


Figure 30 : Relationship between a degree and a mil.

A third system of measuring directions is called 'grad'. 400 grads form a circle. Being divisible by 10, it can be more conveniently expressed in metric system. Its use is, however, not very common.

TRUE, MAGNETIC AND GRID NORTHS

True north is the direction pointing to the North Pole. On a map, true north is represented by meridians or lines of longitude. Magnetic north is the direction which points to the magnetic pole. Magnetic attractions in earth's

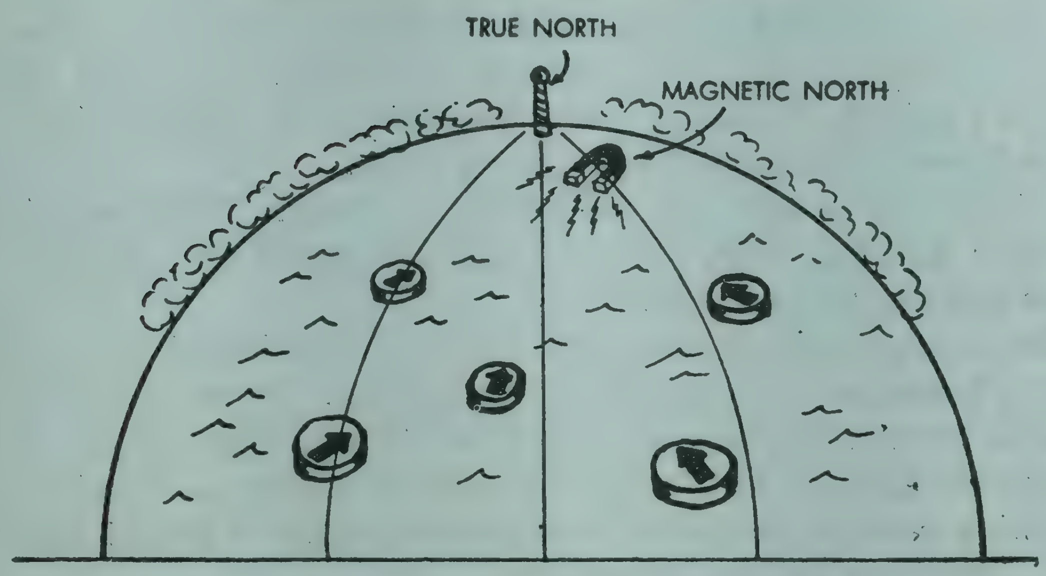


Figure 31 : Magnetic north and true north.

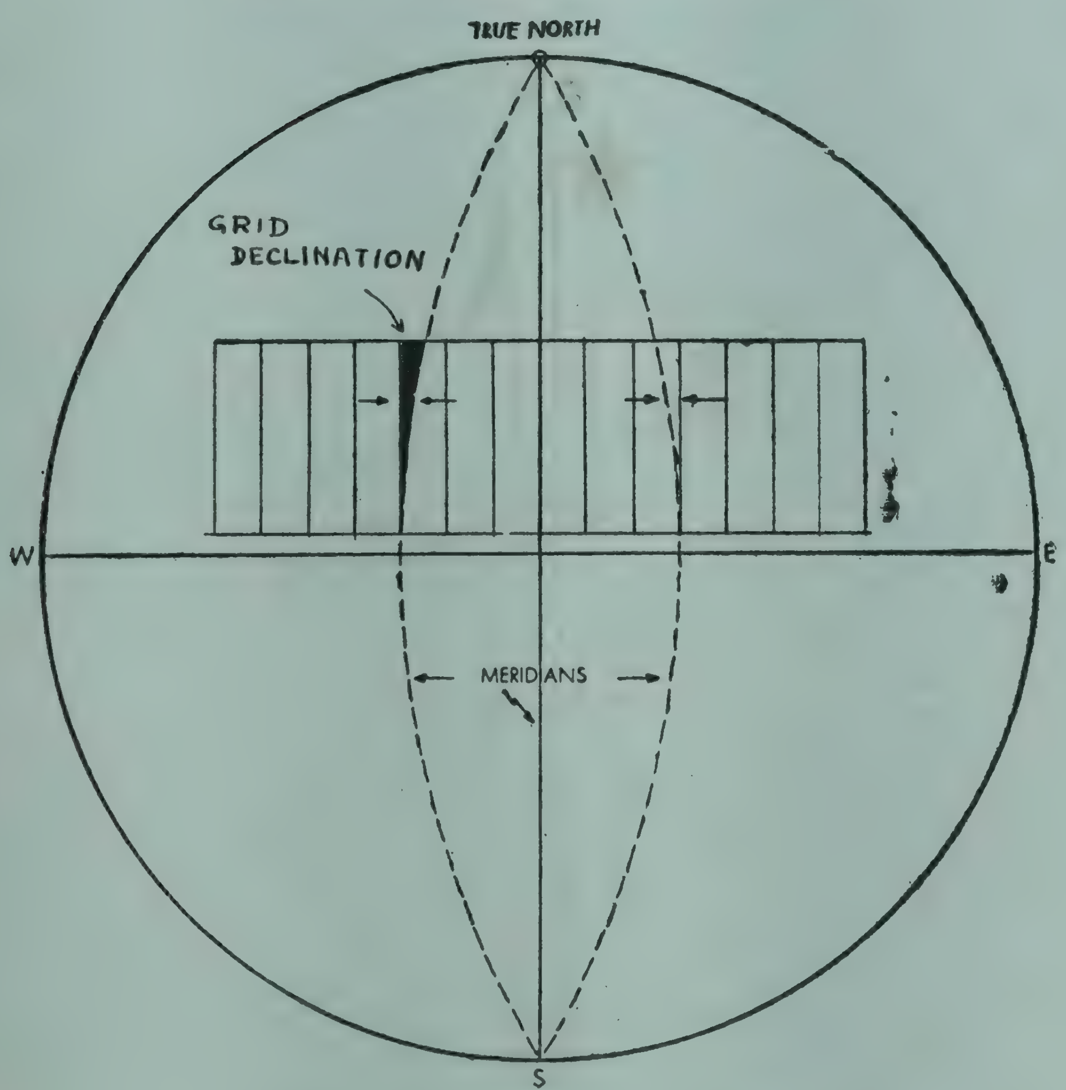


Figure 32 : Grid north and true north.

core cause the needle of a compass to be pulled away from true north. Magnetic attraction differs from locality to locality, depending upon the position of a point with respect to the magnetic pole. Figure 31 shows the difference between the magnetic and the true north.

Grid directions also vary from place to place. These variations are illustrated in figure 32 which shows a grid superimposed on a projection with meridians pointing to true north.

The angular differences in magnetic or grid north and true north are respectively known as magnetic and grid declinations. These values are often given on the margins of topographical sheets. At times they are also expressed diagramatically (fig. 33). As the magnetic declination does not remain constant, maps showing magnetic declination also give the amount of annual change and the year to which the declination pertains.

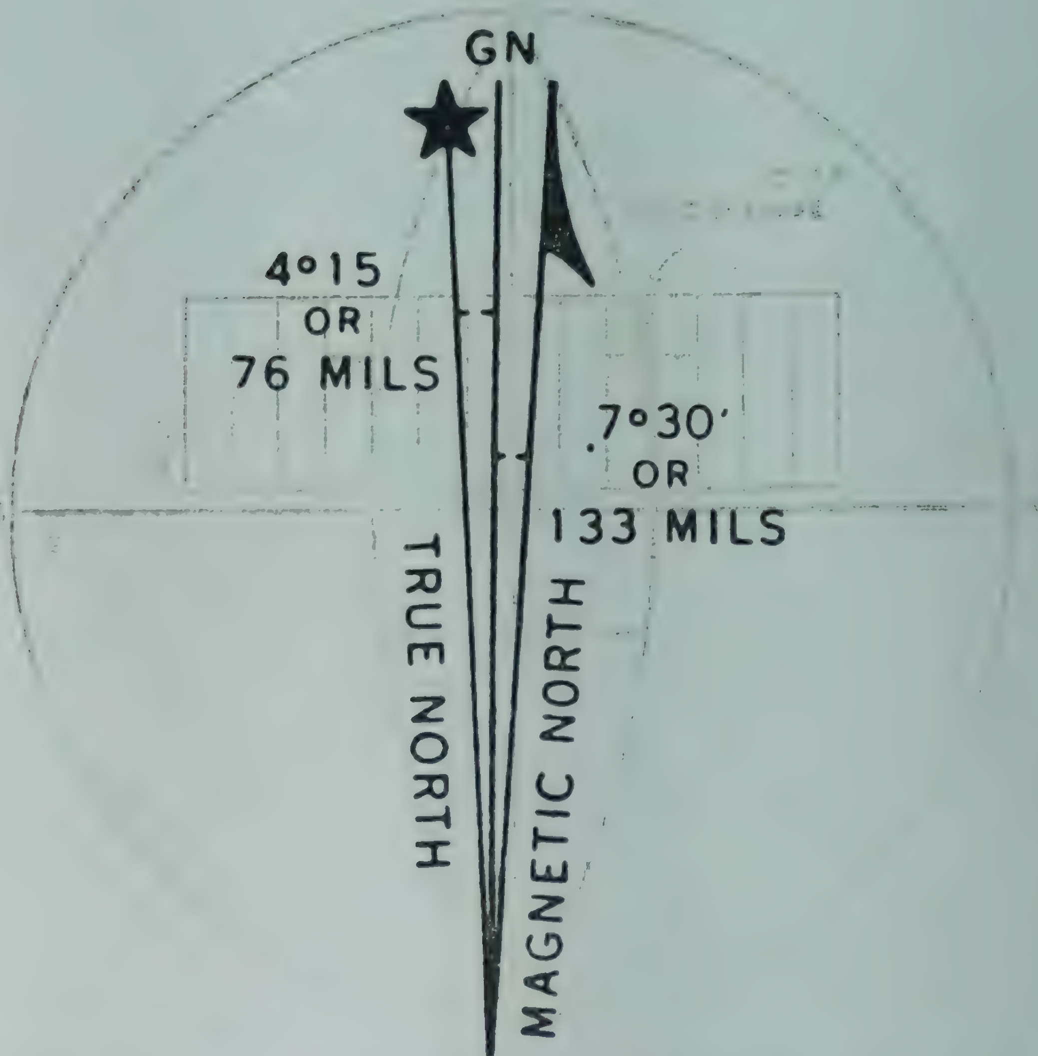


Figure 33: Representation of true, magnetic and grid north on a map.

There are certain points at which the compass needle pointing to magnetic north also points to true north. At these points the true and magnetic norths coincide. The line which joins these points is called 'agonic line'. On two sides of an agonic line, are the lines connecting the points of same magnetic declination. Such lines are called isogonic lines. Maps covering the entire world with isogonic lines are used in determining the magnetic declinations. It is from these maps that we obtain information to construct declination diagrams.

DETERMINATION OF TRUE AND MAGNETIC NORTHS

Using the azimuth :

As stated earlier, a direction angle is always measured clockwise with north as the zero direction. For the sake of convenience, this zero angle is called 'azimuth.' There are three types of azimuths. These are (1) true azimuth (2) magnetic azimuth and (3) grid azimuth. Figure 33 gives the three types of azimuths for the same geographic position.

To determine the magnetic azimuth we use a magnetic compass. The details of this instrument are given in chapter IX. This instrument gives angular values in degrees with reference to the magnetic north. One end of its needle always points to the magnetic north. These angles are known as bearings.

Using the stars :

To determine the true north all that we have to do is to look at the north star. This star always points to the north pole. A similar method is used to determine the true south in the southern hemisphere. These techniques are illustrated in fig. 34.

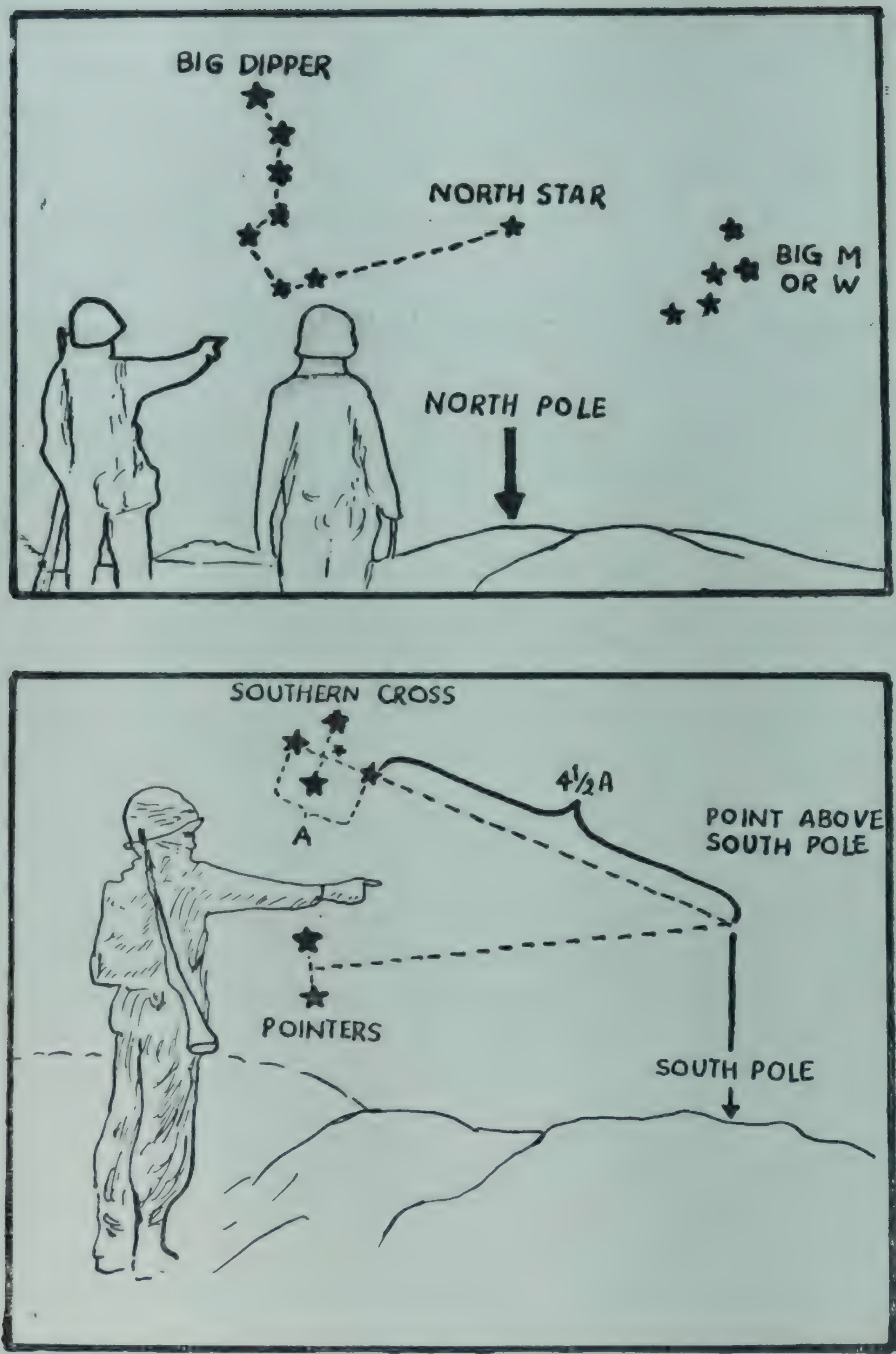


Figure 34 : Determination of the true north and south with the help of stars.

CHAPTER VII

COORDINATES AND THEIR FUNCTIONS

We have already noted that a map is a cartographic representation of the whole or a part of the earth. It is a working model of the earth. To know whether this model represents the earth truly or not, we need a frame of reference which may enable us to compare the details of the earth with that of the model. The most common frame of reference is the system of geographic coordinates. It means a systematic network of lines upon which land and water positions of the earth can be represented. Another frame of reference is known as 'grid system'.

GEOGRAPHIC COORDINATES

To determine the origin and the practical use of geographic coordinates, we must first note two simple facts about the earth. In the first place, and for almost all cartographic purposes, the earth is a sphere. In the second place, it is too large to be dealt with as a single unit. It must be divided in some manner. Geographic coordinates provide the convenient reference points for the determination of location, distance and direction relationships on the ground as well as on the map. Had the earth been flat, the development of the networks of geographic coordinates would have been a simple matter. Because of its spherical shape, principles of spherical geometry involving complicated trignometric calculations have to be used for this purpose.

The principles underlying the division of the earth by a network of geographic coordinates is the same as the preparation of a line graph with X and Y axes. In all graphs we must have a point of origin and two reference lines (1) horizontal line or X axis or abscissa and (2) a vertical line or Y axis or ordinate. As shown in figure 35, we can draw innumerable lines parallel

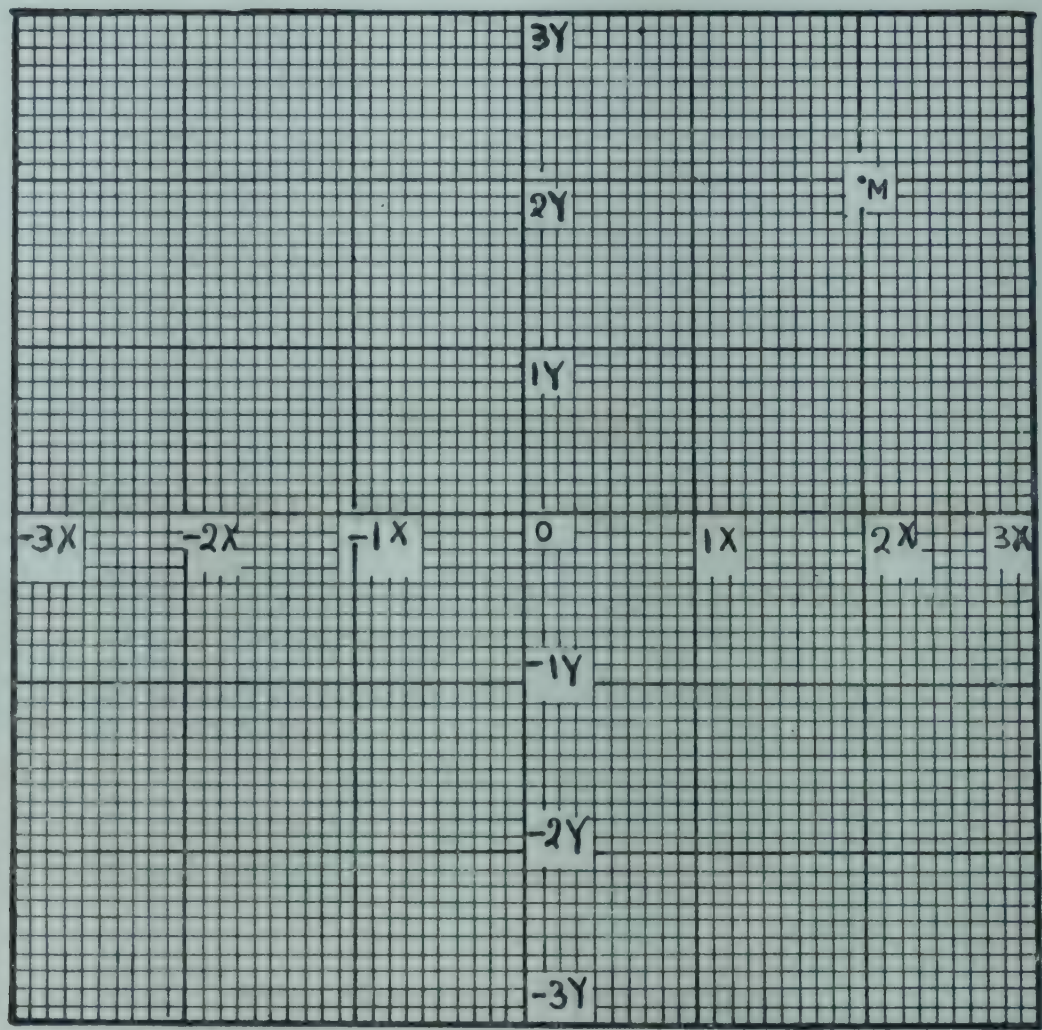


Figure 35 : Locating a point on an arithmetic graph paper.

to OX and OY. The intersection of a pair of these lines will give the location of a point. If we want the location of point M, we can say it is at 2X and 2Y. When a similar set of lines are shown on the spherical earth we call the horizontal lines to be parallels or latitudes and the vertical lines to be meridians or longitudes. The network of these parallels and meridians is called the geographic coordinates.

Parallels or latitudes :

If we represent the earth by a sphere as shown in figure 36 a line drawn mid-way between the northern and southern ends of the axis, will divide the sphere into two halves. This mid-line is called the equator (fig. 36). The latitude means the angular distance from the centre of the earth north or south of the equator. As the equator is the line of origin from which latitudes are measured, it is called 0° latitude. The angular distance between the equator

and the pole is 90° or one-fourths of a circle (360°). As such the latitudes can never be numbered beyond 90°. Latitudes, being the lines parallel to the equator, are therefore called 'parallels'.

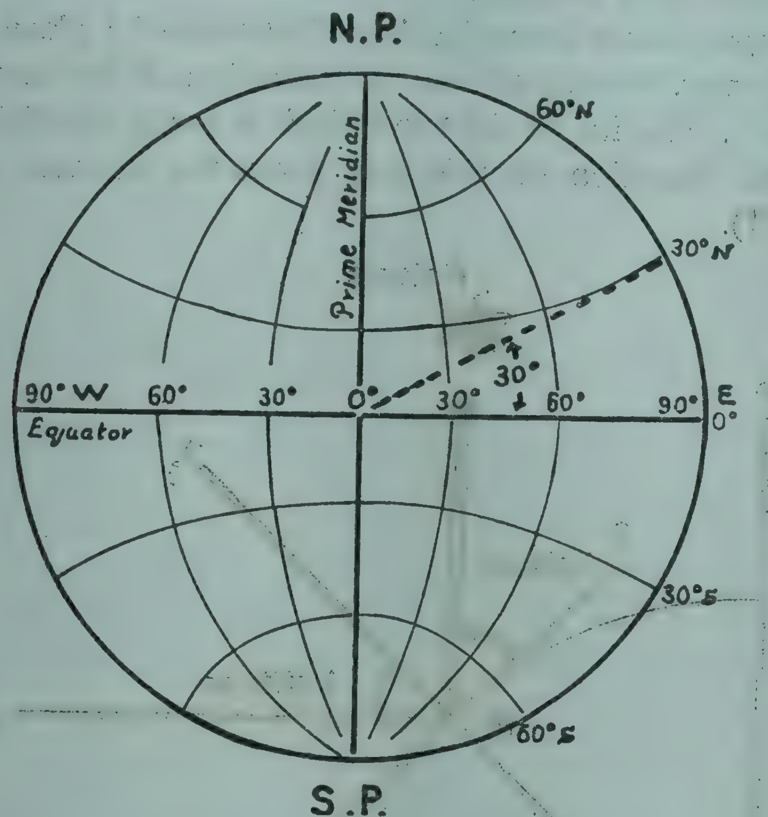


Figure 36 : System of latitudes and longitudes

The shape of the earth being spherical, the determination of the angles of latitudes is a bit confusing. Let us imagine the earth to be cut in half from pole to pole. In figure 37 the earth's polar circumference is drawn as a circle and OE as the equatorial axis. OE and the polar axis OP intersect each other at O. Another line MN has been drawn parallel to the equator to represent a plane of a latitude. Draw a radius (OM) from the axial intersection O to the point M. Extend OM outwards to L. We know that when two parallel lines are cut by a diagonal line, the opposite angles are equal. In this case the equator OE and the plane of the latitude MN are parallel lines and the extended radius OL is the diagonal line cutting the two. Hence $\angle$ MOE = $\angle$ LMN. Angle LMN is 30° and hence the latitude is 30°. And since this latitude is in the northern hemisphere, it is called 30° N.

We can now see that any number of parallels or latitudes can be drawn on both sides of the equator. All these can be determined as explained above. But all these lines may not necessarily be full degree lines. To account for this a degree is divided into minutes and a minute into seconds. In our maps or

globes we find the use of multidegree lines i.e. 10° latitude, 5 degree latitude, etc. This is done with a view to lessen the number of theoretically possible lines. But we must keep in mind that any line drawn parallel to the equator on a globe is a latitude or parallel.

For an approximate determination of latitude of a place we can take the help of the polar star. We can measure the elevation of the north star, (Polaris) above the horizon. The line of sight to Polaris is nearly parallel to the axis of the earth and the elevation of this line above the horizon is equal to the latitude (figure 37).

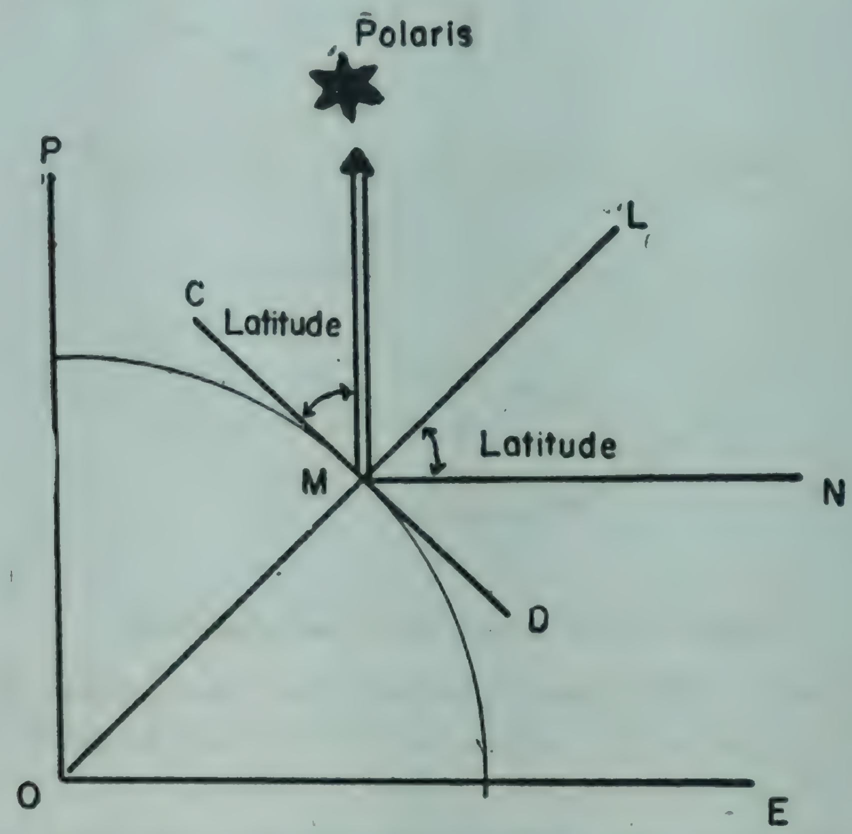


Figure 37: Determination of latitude with the help of the north star.

We can also get the latitude of a place by measuring the declination of the sun at the local apparent noon. This technique is illustrated in figure 38. The elevation of the sun above the equatorial plane is called the sun's declination. This varies with season from $+23\frac{1}{2}$ degrees on the summer solstice through zero at the equinoxes (March 21, and September 22), to $-23\frac{1}{2}$ degrees on the winter solstice. The angle between the vertical and the sun is called the zenith-angle of the sun. It is equal to 90° minus the elevation angle of the sun above the horizon. The sum total of the zenith-angle and the declination is the latitude. On the equinoxes the declination angle is 0. So that the latitude is equal to the zenith-angle.

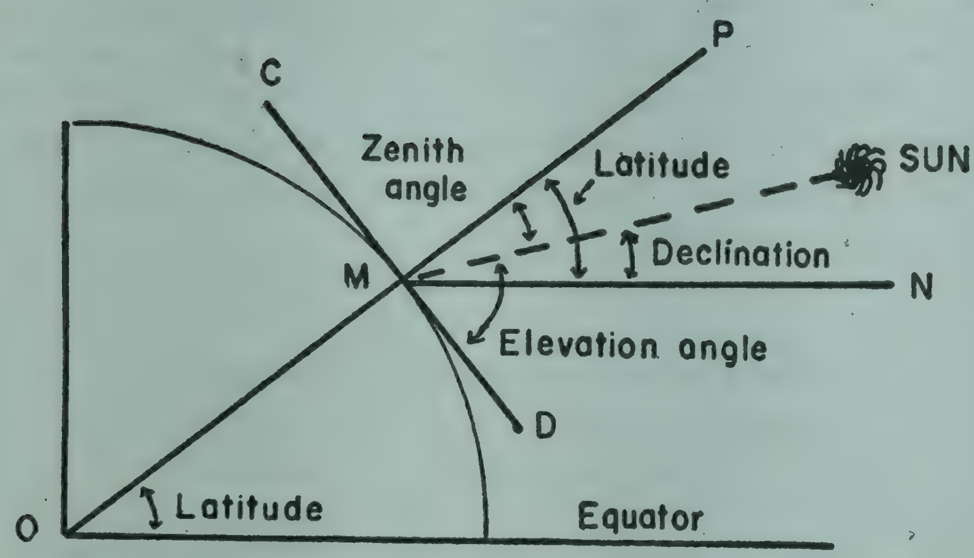


Figure 38 : Determination of latitude with the help of the declination of the sun.

All observers standing at a given distance from the equator but located at different points will record the same angle of declination. If we join these points by a straight line, we will get the plane of that particular latitude or parallel. As the earth is spherical we will get a complete circle for each of the innumerable latitudes.

Meridians or longitudes:

A latitude tells us how far from the equator a point lies. But to pinpoint the position of an object we also have to state where along a particular latitude it is located. Longitudes are the lines running between the north and south poles which divide the latitudes in multitude parts and thus facilitate the derivation of the exact location of any point or object on the surface of the earth. For the determination of longitudes also we take the help of the sun. The earth moves about the sun once in a year (about 365¼ days) and rotates on its axis once in a day (about 24 hours). As a result of these motions of the earth we seem to see the sun move through one complete path in the sky each year and the earth having nights and days. If we line up observers along a straight line running from north to south pole, all of them will see the sun reach its highest point in the sky on any day at the same time. If we had another set of observers along another line east of the first line, they would have already noticed the sun overhead. If there are some other observers on a third line west of the first line, they will have to wait before they watch the sun reaching the highest point. All such lines drawn from pole to pole are called meridians or longitudes.

A meridian is always about one-half of the equator. Unlike the parallels, the meridians are, however, not parallel to each other. The distances between the meridians along succeeding parallels decreases poleward from the equator. The meridians are, however, equally spaced along any one parallel. In all there are 360° of longitudes. Each degree is further sub-divided into minutes and each minute into seconds.

Points of origin:

Just as in a simple graph we have a point of origin, so also in the network of latitudes and longitudes we have to have some common points of origin. For the determination of latitudes, equator is the logical line of origin. Equator is, therefore, called the 0° latitude.

There has never been a dispute over the issue of treating equator as a line of origin. But this has not been the case with the determination of 0 degree longitude. In the past almost every country wanted to have its own 0° meridian passing through a prominent place within it. But as the contacts among different countries increased, the cartographic confusion created by maps drawn with different zero degree meridians could not be tolerated. The earliest attempt to settle this issue was made by an international group of people meeting at Paris in 1634. The dy agreeto treat 19° 55′ 03″ of Paris as the prime (zero degree) meridian. It gradually came to be called Paris meridian, a term the people of other nationalities did not like. To settle the matter, an international conference was held in 1884 at Washington D.C. This conference decided to use Greenwich meridian as the prime meridian. At present all countries use this meridian as the prime meridian. Many of the older maps are based on the prime meridians passing through Ferro (western most of Canary Islands), the Pantheon in Paris (2° 20′ 13.95″ east of Greenwich) Madrid, Oslo, Monte Mario (in Rome) etc.

Notation of Degrees

There are two systems of representing geographic coordinates ; (1) hexagesimal, and (2) centesimal. The former is based on the divisions of sixty where as the latter of hundred. The hexagesimal system is the most commonly used system now. It evolved from the experiences of our ancients who watched the moon wax and wane every 30 days. One moon round was called a month. It took a cycle of 12 months from one spring to another. They, therefore, conceived of a cycle or circle having 30 × = 360 days or degrees. As sixty was and even multiple of 12 and divider 360, of it was considered as an appropriate measuring device for the sub-divisions of degrees. That is why we have 60 minutes in a degree and 60 seconds in a minute.

According to the centesimal system, a circle is divided into 400 grads. Each grad in turn is divided into 100 minutes and each minute into 100 seconds.

The following are the symbols used in writing the two systems. 4 degrees 10 minutes and 15 seconds will be written as $4° 10' 15''$ but 4 grads 10 minutes and 15 seconds will be written as 4^{g} $10' 15''$.

Numbering the Meridians

Once the zero meridian is determined we face the problem of numbering other meridians. We do not face any problem in the case of the latitudes for we start from 0 degree and end at 90°. In the case of the meridians, we have to take a round of 360 degree. If we have a continuous numbering, we will see that 0° and 360° meridians turn out to be the same. In order to avoid this problem, we must stop midway and reverse the order of numbering. That is why we have the meridians starting from 0 to 180 degrees only. Moving eastward the numbering increases to 180° and then decreases back to 0°. Numbers from 0 to 180 are labelled E and from 180 to 0 are labelled W. This makes it possible to locate a point in terms of its latitude north or south of the equator and its longitude east or west of the prime meridian and 180°.

A word of caution must be added here. The east or west labelling of the meridians should not be confused with the direction of movement. One can follow a latitude and go due east or west and reach the same spot without changing the direction. But this will not be the case if one has to go in a north-south direction. Poles are the points from which directions change. One may go along a meridian to north or south to come back to the same spot but one would not travel in the same direction all the way.

ASTRONOMICAL AND GEOCENTRIC LATITUDES

Astronomical latitudes illustrated in fig. 39 are defined as the angles between the direction of a plumb line and the plane of the equator. A plumb line indicates the direction of the gravity of the earth. Geocentric latitude is the angle between a radius drawn from the centre of the earth to a point on the earth's circumference and the equatorial plane, as shown in figure 40. If the earth were a true sphere the astronomical and geocentric latitudes would have been the same.

The latitudes which we have discussed in this chapter in detail constitute a compromise between the astronomical and geocentric latitudes. They are called geographical latitudes. A geographical latitude is the astronomical latitude corrected for the so called "station error" i.e. local gravity anomalies. The lines of astronomical latitudes are wiggly whereas those of the geographic

latitudes are perfect circles. The difference between the geocentric and geographic latitude is less than 12 minutes of an arc.

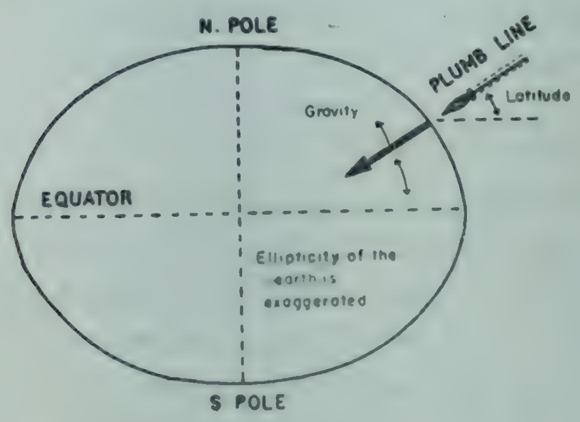


Figure 39: Astronomical latitude

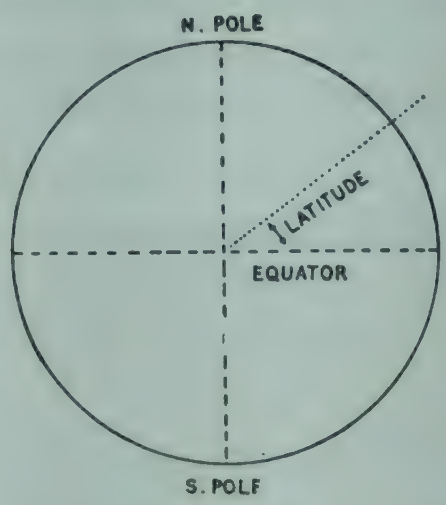


Figure 40: Geocentric latitude

INTERNATIONAL DATE LINE

The earth rotates from West to East, causing the apparent movement of the sun from east to west. The full circle (360°) rotation of the earth is completed in approximately 24 hours or 15 degrees per hour. In other words the sun traverses 15 degrees of longitude from east to west every hour or 1 minute of longitude every 4 seconds of time. The local apparent noon time changes by one hour for every 15 degrees of longitude. The time decreases as one goes to the west, as the sun also moves with the traveller and increases as one moves eastward. By international agreement the day begins at about longitude 180° which passes through Pacific Ocean. This is called the International Date Line. The International Date Line does not follow 180° longitude all the way in order to avoid passing through land. This is necessary to do otherwise the country or island through which it passes will have two different dates. When crossing the International Date Line from East to West one gains a day. Thus if it is 6 A.M. on January 10 on the eastern side of the line, it will be 6 A.M. on January 9 on the other side. Similarly while crossing the line from West to East one loses a day (fig. 41).

For the purposes of common time keeping, it is necessary to define time zones within which all clocks read the same time. If it is not done, people living at different longitudes within the same country will have different times. The time zones are approximately 15 degrees of longitude wide. The central meridian of the zone defines the standard time within the zone. India has only one time zone whereas the USA has four.

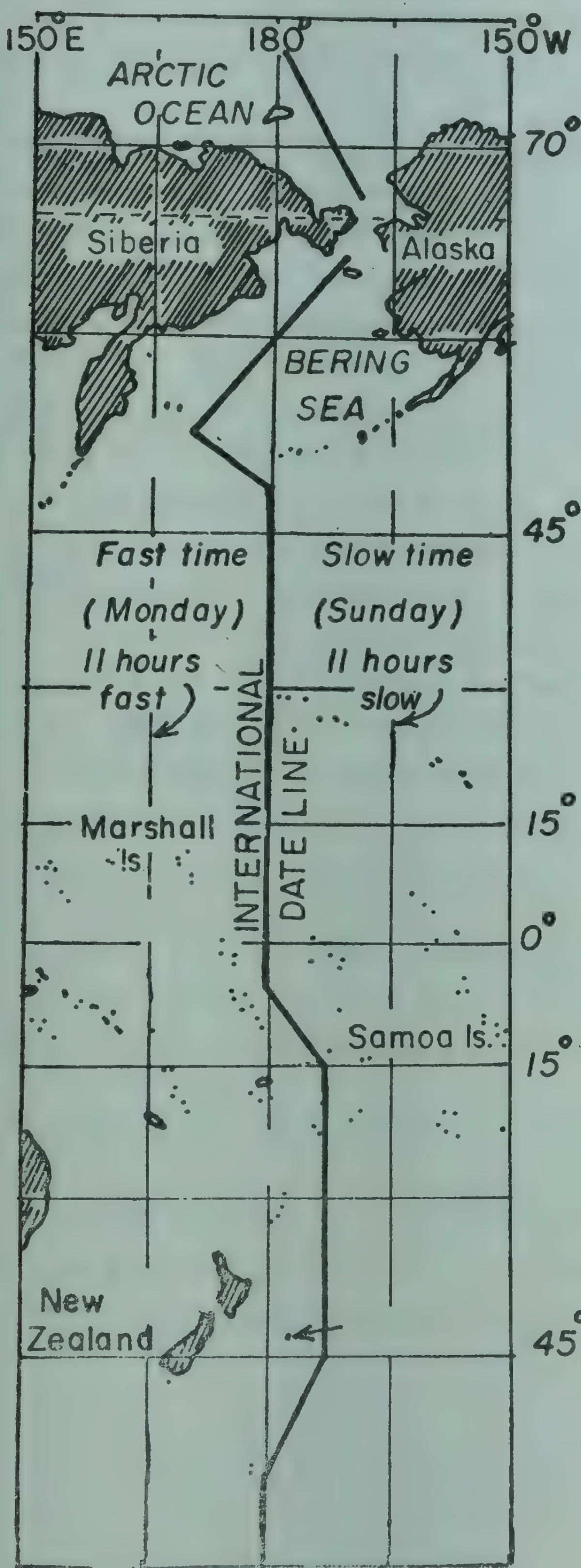


Figure 41 : International Date Line

THE GRID SYSTEM

Another reference system in common use is the so-called grid system. It has been developed as a common-language means of locating points on a map.

A grid is a net-work of a series of vertical and horizontal lines constructed perpendicular to each other. One series of lines runs from east to west and the other from north to south. Together they form squares of same dimensions within a given map. Each of the line forming the squares is given a value so that the position of an object on a map can be easily identified.

Grids are generally used on maps with 1 : 250,000 or larger scale. On small scale maps, point locations can be better done with reference to longitudes and latitudes. Maps on 1 : 250,000 or smaller scales have grid markings at an interval of 10,000 units, but those having larger scales have 1000 unit intervals. The units may be yards, feet or meters.

Every grid line on a map is identified by a number printed in the margin of the map, directly opposite the relevant grid line. The numbers for the vertical lines are given on the bottom margin and for the horizontal lines on the right hand margin. In some cases these numbers are given on all the four sides. The point of origin of the grid line is always the South–West corner of the sheet. The numbers, therefore, increase in northerly and easterly directions.

Grid numbers have several digits. To accommodate several digits and at the same time to keep them legible, all the digits are not given. On maps with larger than 1 : 250,000 scale, the last three digits are omitted. On maps with 1 : 250,000 scale, the last four digits are omitted. To indicate the true values, one north and one east grid values are printed in full in the South-West corner (figure 42).

The rule for reading the grids is READ-RIGHT-UP. That is to say that first read eastward to the right across the bottom of the grid and then northward up the side. Suppose the given value is 969091. Here 91 and 09 represent the south-west corner of the squre in which the point is located ; 6 stands for 6/10 of the way from 91 to 92 and 1 stands 1/10 of the way from 09 to 10 (figure 42).

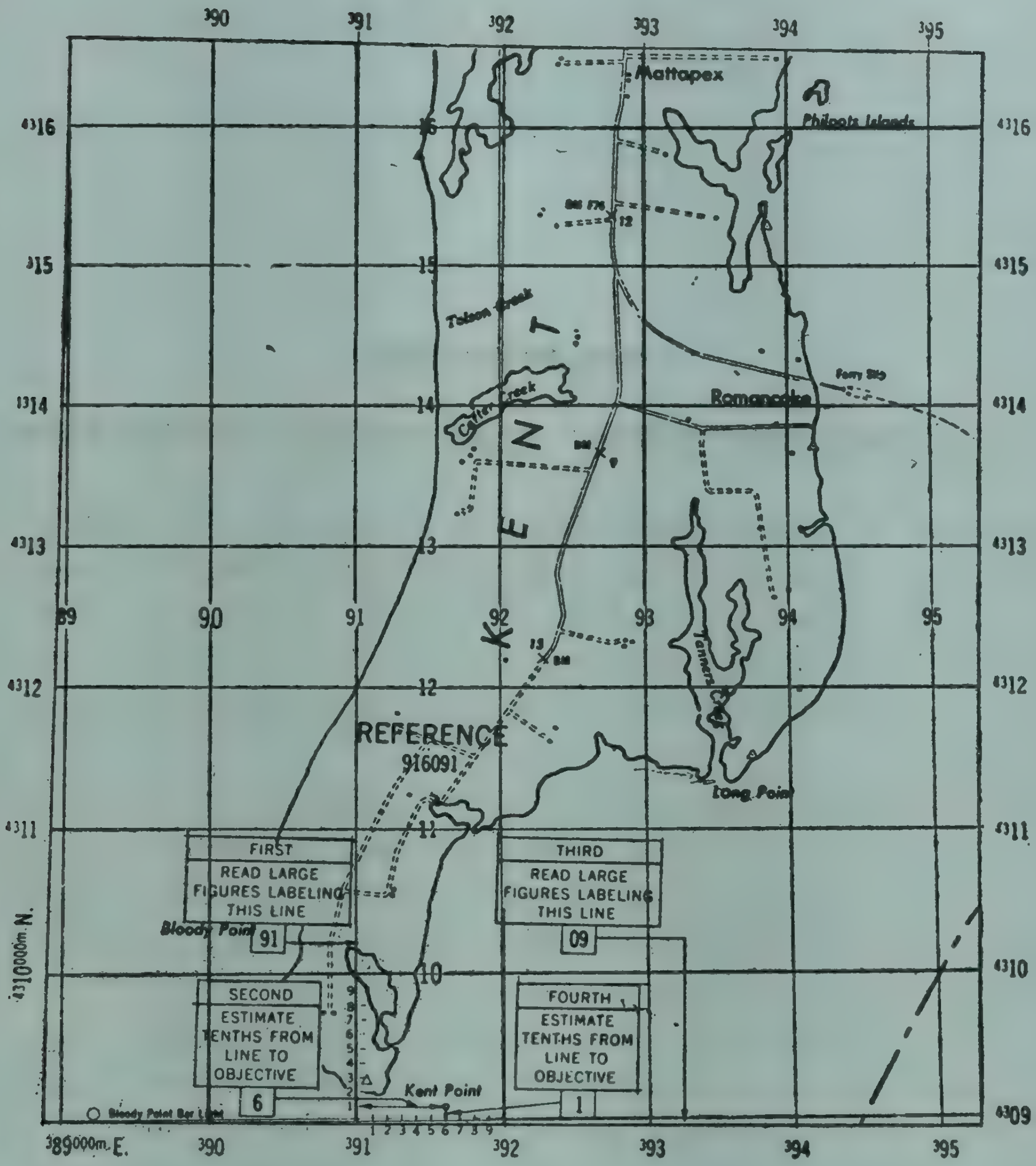


Figure 42: Reading the grids. (From Map Reading).

CHAPTER VIII

MAP PROJECTIONS AND THEIR FUNCTIONS

The task of cartographers would have been far less complex had our earth been flat. Because of the spherical shape of the earth and the plane surface on which this shape has to be represented, cartographers have to devise complex graphical, geometrical and mathematical methods of transforming the earth. The resulting transformations are collectively known as map projections.

The dictionary meaning of the word ' projection ' is to project an image on something. In the case of a map projection, we project the network of latitudes and longitudes of a globe on a plane surface. It is, however, only in few cases that we get map projections by this method. In most other cases we use geometrical and mathematical methods to derive the networks of longitudes and latitudes. Nevertheless the graticules so derived are called projections. In view of this, we will define a map projection as the transformation of the spherical network of latitudes and longitudes on a plane surface, irrespective of the method of transformation.

AN IDEAL MAP PROJECTION

An ideal map projection is one which represents the meridians and the parallels in the same way as a globe. The global network of meridians and parallels has the following characteristics:

1. The equator divides the globe into two halves—the northern hemisphere and the southern hemisphere.
2. The equator is perpendicular to the polar axis.
3. All the parallels are parllel to the equator.
4. The spacing between any two parallels is the same along all meridians.

5. The equator is the only great circle line of latitude. All other lines of latitude (parallels) are shorter than the equator and are not great circles.
6. Each meridian is one half a great circle in length. It is the shortest line between the two poles.
7. All meridians converge at the north and south polar points.
8. The spacing between meridians is equal along a given parallel, but the space between meridians decreases polewards.
9. The parallels and the meridians intersect at right angles ; and
10. All areas are in correct scale ratio to earth measurements.

Because of the above noted characteristics, a globe possesses the following properties :

1. It represents the features of the earth's surface in their true shape. It, therefore, has the property of *conformality.*
2. All the features represented on it maintain their proportional sizes. It, therefore, has the property of *equivalence* or *equal area.*
3. Geodetic lines on the earth which give the shortest distance between any two points appear as shortest lines on the globe. In other words, the *distances are correctly maintained.*
4. The directions of points on the globe from a given point are the same as the directions on the surface of the earth. In other words *directions are truly represented* on a globe.
5. The longitudes and latitudes are so arranged that it is convenient to locate a point. In other words the network of graticules has the property of *simplicity.*

It has been the endeavour of cartographers since early times to develop a projection which has the same properties which a globe has. This could be achieved, only if a projection possessed the ten global chararcteristics noted above. In view of the fact that it is not possible to represent the globe on a flat surface without losing one or several of the above noted characteristics, it has not been possible to develop a projection which satisfies all the five global properties.

COMPROMISES OF EXISTING PROJECTIONS

Any large part of a spherical surface cannot be represented on a flat surface without shrinking, breaking or stretching it somewhere. It is, therefore, impossible to lay out a flat unbroken network of lines that will conform to the networks of a globe. As such it is not possible to achieve all the five properties required to make a perfect map. It is, however, possible to

develop projections which have one or more of the properties though not all of them.

Conformality or orthomorphism :

The term conformality implies that the shape of the map surface at any given spot is identical to the shape of the corresponding spot on the earth. Here the use of the word *spot* should be noted. Implications of term conformality are sometimes wrongly enlarged to cover overall shapes of large areas like continents. A correct interpretation of the term implies that the shapes of small areas and spots would also be correctly maintained.

The angle at which the parallels intersect the meridian governs the shape of areas. On a globe, each meridian crosses each parallel at a right angle. Preservation of the right angle and the maintenance of the same scale both along the parallel and merdian makes a projection conformal.

True Directions :

Directions are correctly shown on conformal projections. The Mercator's projection was developed for the purpose of retaining true directions, not only along projection lines but also diagonally between them. This could be achieved by a uniform distortion of the network intervals. Another way of maintaining correct direction is to evolve a projection which is constructed on a plane from one central point. In such projections, directions of all point on a map, as taken from the central point, will be the same as between corresponding points on the ground.

Equal Area or Equivalence :

A conformal projection cannot be equivalent. And *vice versa* is also true. An equal area map preserves the ratio of mapped area to the corresponding earth area. To preserve equivalence between a given area shown on spherical and flat surfaces, shape must be sacrificed or compromised.

To have the property of equivalence, a projection must possess two properties (1) The parallels and meridians should be drawn to scale, and (2) the spacing between the parallels and meridians should be true. Most equal area projections are mathematically derived.

True Distances :

Distances are true along the parallels which are drawn to scale and spaced correctly. Similarly the distances along the meridians drawn and spaced correctly are also true.

TYPES OF MAP PROJECTIONS

There can be as many types of map projections, as the criteria used for classification. The following are the most frequently used classificiations :

Serial No.	*Criteria*	*Types*
1	Method of derivation (source of light)	I. Prespective II. Non-Perspective III. Mathematical or conventional
2	Developable surface	I. Conical II. Cylinderical III. Azimuthal or Zenithal IV. Mathematical or conventional
3	Global properties	I. Homolographic or equivalent or equal area II. Orthomorphic or conformal III. Azimuthal or correct bearings

Perspective projections are those which can be derived by projecting the image of the network of meridians and parallels of a globe on any developable surface. Many projections have been evolved as slight modifications in the developable surfaces. The lines forming the network are straightened or curved and the spacings between the parallels and the meridians are reduced or enlarged to make a perspective projection equivalent, orthomorphic or azimuthal. Such projections are called non-perspective projections. All non-perspective projections are also non-developoble projections because they can never be transferred by means of a source of light casting shadows on surfaces capable of being flattened. They are, nevertheless, considered to be developable because they can be derived by simple modifications in perspective projections. Mathematical or coventional projections are those which are derived by mathematical computations and formula and have little, if any, relation to a projected image.

The developable projections are classified as (1) conical (2) cylindrical and (3) zenithal. A developable surface is one which can be flattened and

which can receive lines projected or drawn directly from an assumed globe. To derive a projection on a cone, we will have to wrap a cone around a globe. If we place a light in the centre of the globe, it will cast shadows of the geographic network on the inner surface of the cone. When the shadow net is drawn and the cone is cut open and laid flat, we will get a projection in a working position. Cylindrical projections can be derived the same way. When a plane touches the globe at a point, we get a zenithal projection. The method of deriving projections from developable surfaces, is illustrated in figure 43.

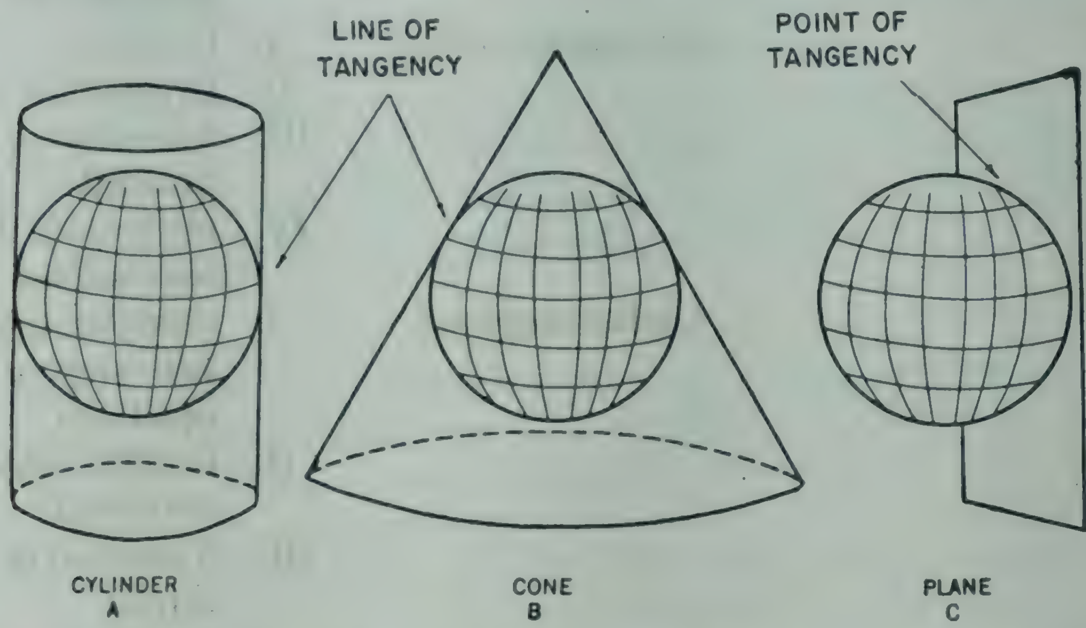


Figure 43 : Methods of deriving map projections from developable surfaces.

Projections can also be classified on the basis of the global criteria they satisfy. These criteria are (1) equivalence (2) orthomorphism and (3) correct bearings. Such projections can be developable as well as non-developable. They can be conical, cylindrical, zenithal and mathematical.

The above classifications of map projections reveal that there is no way of classifying projections into mutually exclusive classes. Most projections fall into two or more of these classes.

CONSTRUCTION OF MAP PROJECTIONS

Before we embark on the construction of the various types of map projections, we must first know some of the bases on which they are constructed. First of all we must know the scale on which the projection is to be drawn. We must reduce the true earth measurements to the scale we want to have the projection. We know that the equatorial circumference of the earth is about 25,000 miles (24,890 miles) and the mean radius 4000 miles (3963. 2261 miles).

The radius of the earth when converted into inches amounts to about 250,000000″. Thus, if we have to make a globe of 1″ radius it will be 1/25 m. the size of the earth. The length of the equator on the globe will be equal to the circumference $2\pi R = 2 \times \frac{22}{7} \times 1'' = 6{\cdot}3$ inches. From the equator we have to build the network of latitudes and longitudes. One degree of latitude is equal to about 69 miles, although it varies from 69·5 miles near the equator to 68·7 miles near the poles. A degree of longitude, however, has too great variations (table 1).

Table 1: Length of a Degree of Longitude along Various Latitudes.

At Latitude	*Length of the degree longitude*
0	69.6 Miles
10	68.3 ,,
20	64.8 ,,
30	59.9 ,,
40	52.9 ,,
50	44.6 ,,
60	34.8 ,,
70	23.7 ,,
80	11.8 ,,
90	0 ,,

To find out the length of each parallel, we can use a graphical or a mathematical method, depending upon the degee of accuracy desired. If we need only approximate measurements, we can use a praphical method as illustrated in figure 44. Supposing that we want to find out the length of

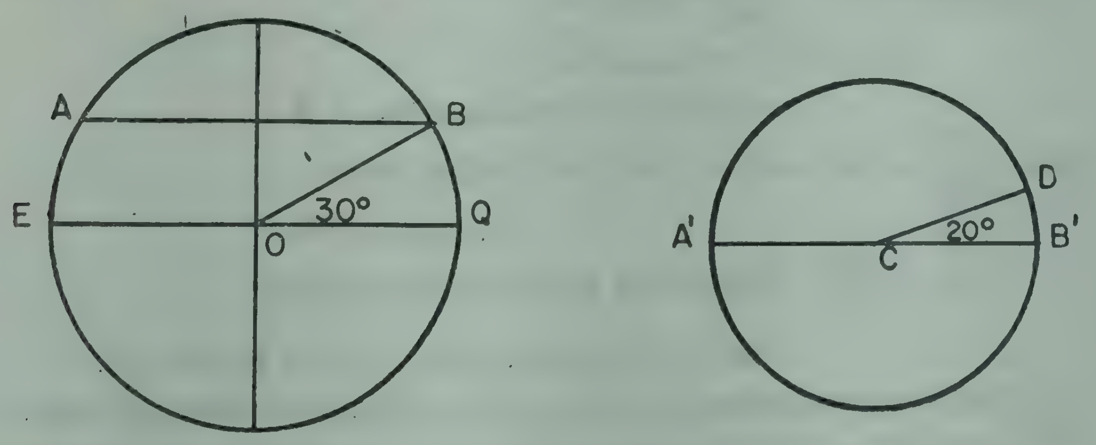


Figure 44: Graphical method of determining the length of a parallel.

30 degree parallel. Draw a circle with the given earth radius. Let EQ be its diameter. Draw OB making angle QOB equal to 30 degrees. Draw AB parallel

to EQ. With AB as diameter, draw another circle A′ B′ D. From its centre C draw DCB′ the angle of desired interval. The arc distance DB′ is the required longitudinal interval along 30 degree parallel. To get the length of 30° parallel, all that we have to do is to multiply DB′ by $\frac{360}{\text{interval}}$.

If greater accuracy is desired, we should use a mathematical method. This method is illustrated in figure 45. OE is the radius (R) of the circle. AB is a parallel drawn at 45 degree latitude.

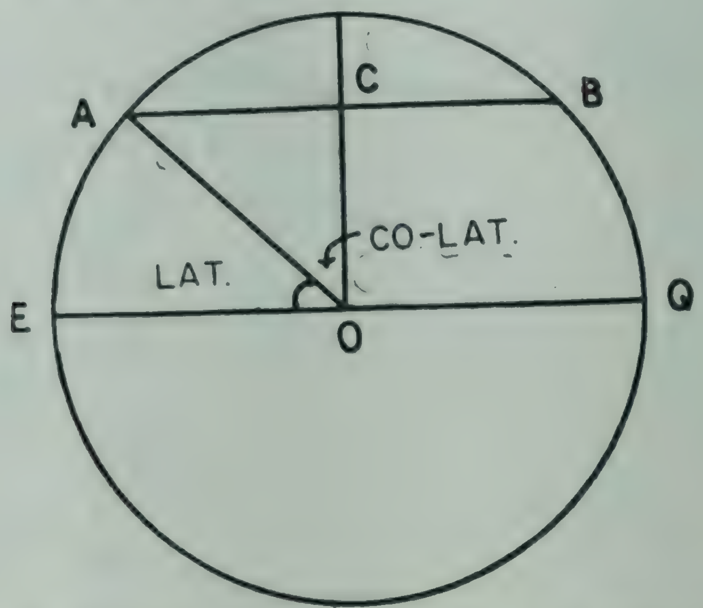


Figure 45: Mathematical method of determining the length of a parallel.

Angle OAC = angle EOA = latitude (being alternate opposite angles.)
Angle AOC = 90° — Lat. = co-lat.

In triangle OAC, $\frac{AC}{AO}$ = cos. lat.

Or AC = AO cos. lat.

= R cos. lat. because AO = R

Since $\frac{AC}{AO}$ = Sin. co-lat.; AC = AO Sin. co-lat.

= R Sin. co-lat.

AC = $\frac{AB}{2}$. Hence the length of the parallel

AB = 2 π R sin. co-lat. = 2 π R cos. lat.

The length of any other parallel can be determined the same way.

Thus when R = 1″ the length of the arc of the parallel AB for an interval of 10° will be.

$$\frac{2\pi R \cos. \text{lat.} \times d}{360} = \frac{2\pi R \cos. 45^\circ \times 10}{360} = \frac{2 \times 22 \times 1 \times 0.71 \times 10}{7 \times 360} = .12''.$$

PERSPECTIVE CONICAL PROJECTION

As already explained when the image of the network of parallels and meridians is projected on a developable cone, we obtain a conical projection. In figure 46, PQ is the circle of contact or tangency. Such a circle (parallel) along which the cone is tangent to the globe is called the *standard parellel.*

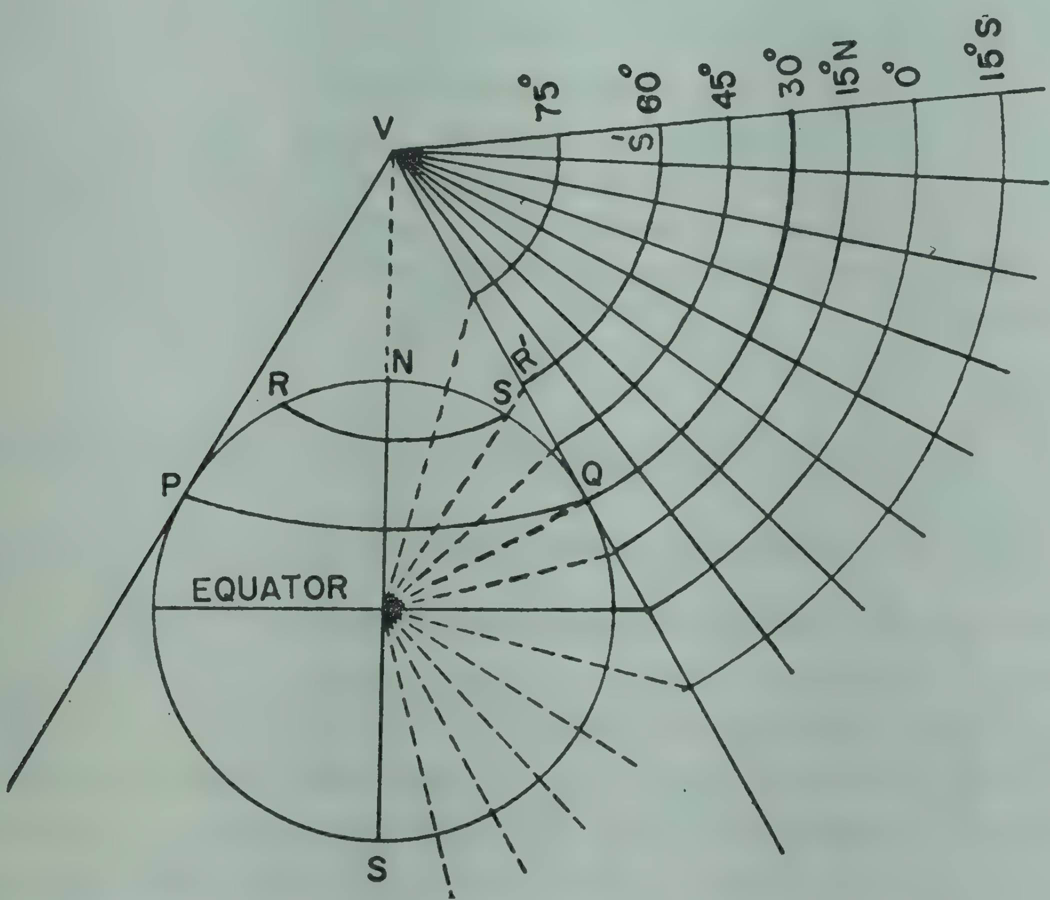


Figure 46: Derivation of a perspective conical projection.

A perspective conical projection is one which is derived by projecting the image of the network of parallels and meridians of a globe on a developable cone which touches the globe along a standard parallel. The light is supposed to be located at the centre of the globe. As the cone touches the globe along PQ, the position of this parallel on the globe coincides with that on the cone. But the position and length of other parallels on either side of the standard parallel are distorted. For example, parallel R S on the globe is shifted up as R′ S′ on the cone. Its length is also considerably increased. The north pole is shifted from N to V. The distortion of shape and area away from the standard parallel is so progressive and so much that this projection cannot be used for anything except representing areas along the standard parallel.

To minimise the distortion in shape and area a number of non-perspective conical projections have been developed. A few of the important ones are discussed below.

SIMPLE CONICAL PROJECTION

A simple conical projection is an improved version of the perspective conical projection. This projection also has only one standard parallel which is true to scale. All the parallels are drawn as concentric circles. It differs from the perspective conical proejction in the spacing of the parallels. In the perspective conical projection the distances between the parallels increase progressively as one moves to north or south of the standard parallel ; in the simple conical projection the parallels are drawn at equal intervals. As a result the distortions in shape and area away from the standard parallel are considerably minimised.

Construction :

For the graphical construction of this projection the following procedure may be adopted :

Determine the radius of the earth from the given scale. If the scale is $1=250{,}000{,}000$, the radius of the reduced earth will be $\frac{250{,}000{,}000}{250{,}000{,}000}$ inches $=1$ inch. Draw a circle with a radius of 1 inch to represent the earth (figure 47). Draw the angle for the standard parallel (in this case AOT$=45°$) and of the given interval (in this case AOB$=15°$). Tangent TP is drawn at T to meet the polar axis of the reduced earth at P. With AB as radius draw an arc of a circle with O as the centre. Draw XY parallel to EA. PT is the radius of the standard parallel ; AB is the interval between the parallels along the central meridian and XY is the interval between the meridians along the standard parallel.

Now draw a straight line VV′ to represent the central meridian. With O′ as the centre and PT as the radius, draw an arc of a circle to represent the standard parallel. Starting from the intersection of the standard parallel and the central meridian, mark intervals along the central meridian and the standard parallel. With O′ as the common centre, draw arcs of circles through the points marked on the central meridian to represent other parallels. Join O′ with the points marked on the standard parallel. This gives the required graticule for the simple conic projection.

For mathematical construction, the following procedure can be adopted. Determine the length of the radius of the standard parallel$=$R cot. latitude, where R = radius of the reduced earth. The length of the standard parallel

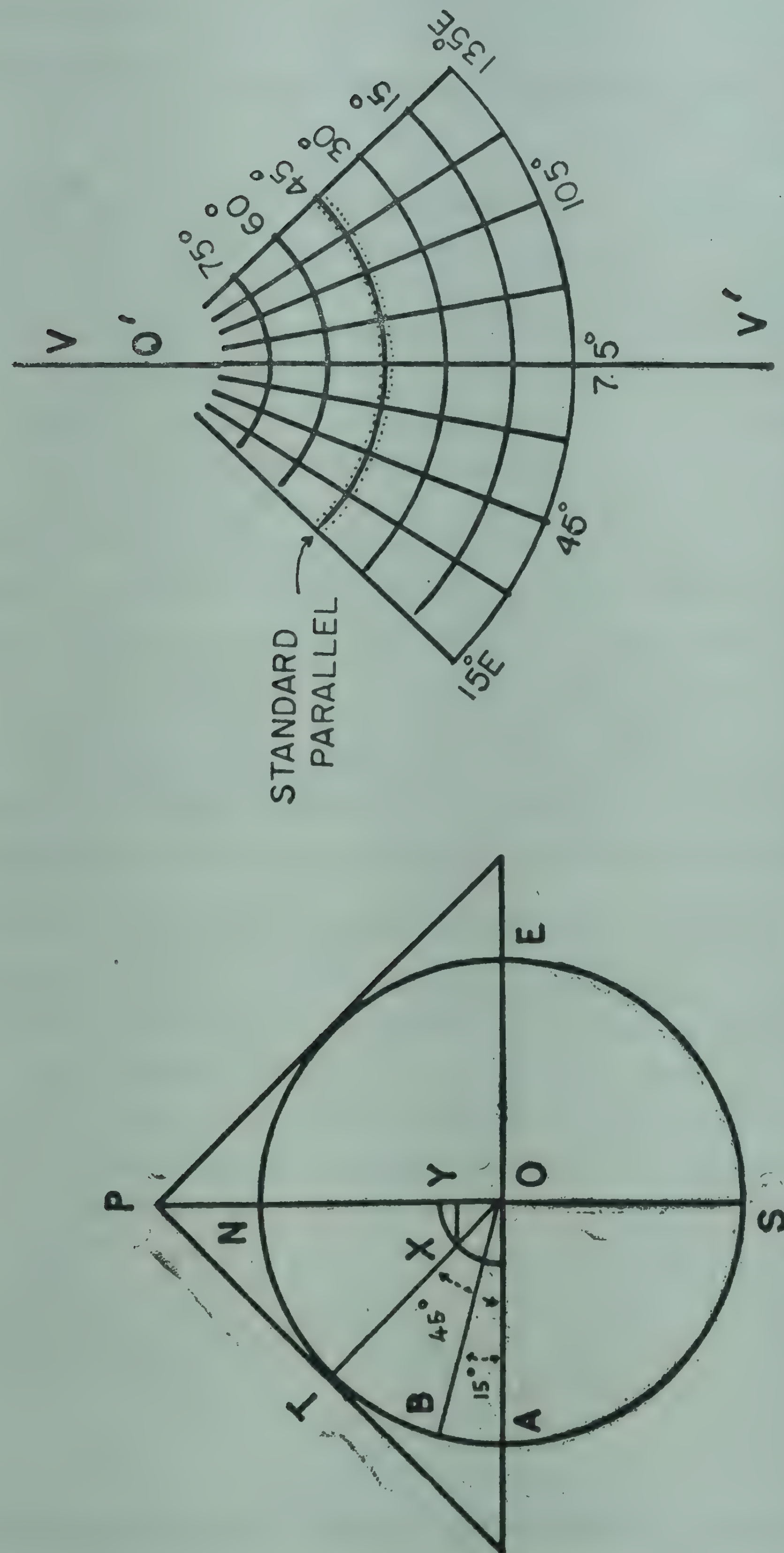


Figure 47 : Simple conical projection.

equals $2\pi R$ cos. lat. and the intervals between the meridians along the standard parallel equal $\frac{2\pi R \text{ Cos. Lat.} \times \text{Interval}}{360}$. The intervals between the parallels along the central meridian are derived by the formula $\frac{2\pi R \times \text{Interval}}{360}$.

Properties and Uses :

This projection is a modified version of the perspective conical projection. Its parallels form arcs of concentric circles and are equally spaced. The standard parallel is the only parallel which is truly divided and hence is the only parallel along which the scale and the distances are correct. The meridians are equally spaced along the parallels. They converge toward the pole but do not meet. The pole is represented by an arc of a circle. The vertex of the cone does not represent the pole. Distances between the parallels are the same along all the meridians. Distances along the meridians are fairly accurate. Shape and area represented are generally well maintained near the standard parallel. Great circles can be represented by near straight lines anywhere on the projection and are straight lines along the meridians. It is not used for world maps because there are extreme distortions in the hemisphere opposite the one in which the standard parallel is selected. Even within the same hemisphere, distortions both toward the pole and the equator are large enough to discourage its use for representing a hemisphere. It is most suited for mapping middle latitude areas of limited latitudinal and relatively larger longitudinal extent.

CONICAL PROJECTION WITH TWO-STANDARD PARALLELS

The simple conical projection with one standard parallel has been modified by selecting two, instead of one, standard parallels to get this projection. The standard parallels should be so selected that they enclose about two-thirds of the latitudinal extent of the area to be represented. For example, if the area to be represented extends from 20°N to 60°N, the standard parallels will be 30°N and 50°N. This should not, however, be treated as a rule. The selection will partly depend upon the purpose of the map and the area to be emphasized. By making a judicious choice of standard parallels, one can represent much larger areas fairly accurately than one can do on the simple conic projection (figure 48).

Construction :

Draw a circle or a quadrant of a circle with the given reduced earth radius. Draw angles of latitudes for the two standard parallels and the selected interval along the parallels and the meridians. As a cone resting on a sphere

cannot touch it along two parallels tangentially, it is made to cut across the sphere keeping the strips of the sphere between the two standard parallels outside the cone.

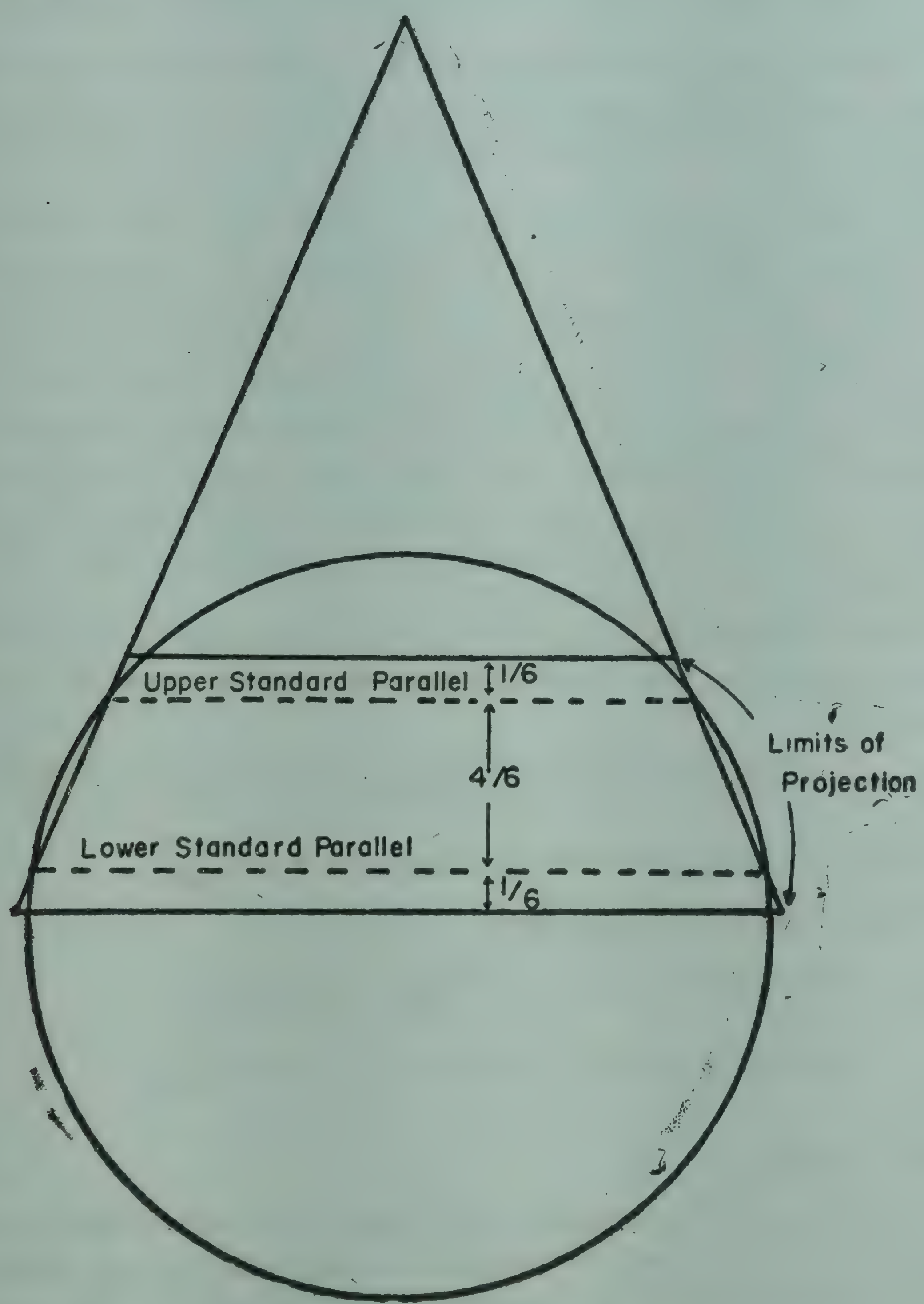


Figure 48 : Selection of standard parallels for conical projection with two standard parallels.

The procedure for getting measurements for graphical construction is the same as in the case of the simple conic projection. To get the vertex of the

cone, draw a straight line CD as given in figure 49. Take the distance EF and mark the required number of divisions on CD. EF can also be calculated by the fomula $2\pi R \times \frac{\text{Interval}}{360}$. The intervals in figure 49 are 10° degrees apart. From H and L which represent the intersections of 20° and 50° degree parallels and the central meridian, draw perpendiculars HG and LK equal to XY and MN respectively. Join GK and produce it to meet CD at C. Point C will form the vertex of the cone.

To construct the projection, draw a vertical line C′ D′ representing the central meridian. Divide this line in the same way as CD. Among the divisions, locate points H and L to represent the intersections of 20° and 50° parallels and the central meridian. Take CH and CL as radii and draw arcs of concentric circles with C′ as the centre passing through H′ and L′. These will constitute the two standard parallels. Draw the other parallels also as concentric circles with centre C′. Take distances GH and KL and divide the respective standard parallels on both sides of the central meridian as shown in figure 49. Join the corresponding points on two standard parallels by straight lines and extend them poleward as well as equatorward.

The mathematical construction of the projection is easier than the graphical construction. The following formulae can be used to get various measurrments :

Intervals along the standard parallels $= 2\pi R \cos. \text{Lat.} \times \frac{\text{Interval}}{360}$

Intervals along the central meridian $= 2\pi R \times \frac{\text{Interval}}{360}$.

Radii of the standard parallels

First parallel (y) $= 2\pi R \frac{y-x}{360} \cdot \frac{\cos. x}{\cos x - \cos y}$.

Second parallel (x) $=$ Radius of $y + 2\pi R \frac{y-x}{360}$.

Properties and Uses:

As in the case of the simple conic projection, in this projection also the parallels are drawn as arcs of concentric circles and are equi-spaced. The meridians appear as straight lines and converge at the vertex. The scale is true along the standard parallels. Distances are reduced between the standard parallels and are increased outisde them. The pole is represented by an arc of a circle. It does not coincide with the centre of the circles forming the parallels. The intervals between meridians on any given parallel are equal, but they are

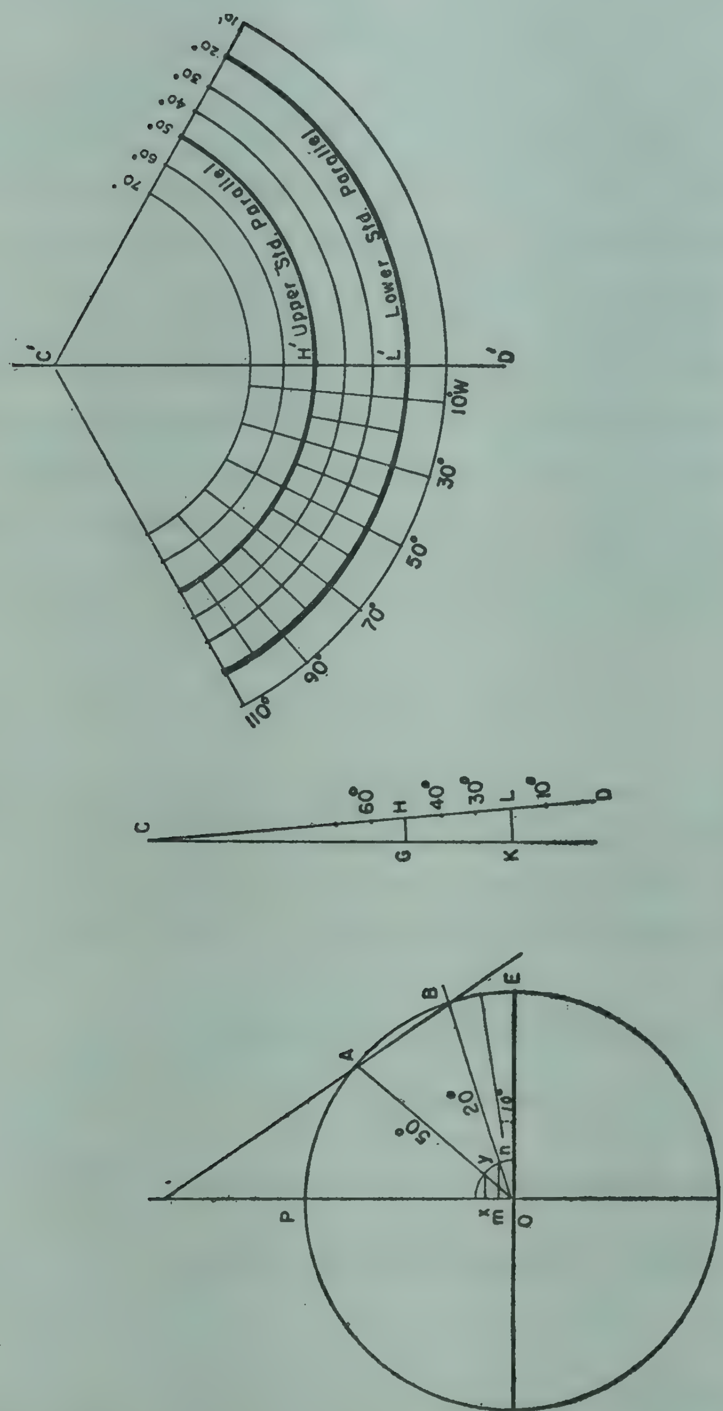


Figure 49 : Conical projection with two standard parallels.

progressively reduced as one goes toward the pole. This projection, being an improved version of the simple conic projection, is suited to middle latitude areas having about 50° latitudinal extent. It can be used for showing Trans-Siberian Railway, Canada, U.S.S.R. and also, to some extent, China.

BONNE'S PROJECTION

This projection is also a modified version of the simple conic projection. It has only one standard parallel but each parallel is truly divided. It is an equal area projection. The method of finding out the radius of the standard parallel is almost the same as in the case of the simple conic projection. All the parallels are equi-spaced and drawn as arcs of concentric circles from a common centre. The central meridian cuts all the parallels at right angles and the standard parallel cuts all meridians at right angles. The length of the parallels is true with reference to the globe. The distance between any two given parallels along the central meridian is true and constant. It must, however, be noted that no other parallel or meridian except the standard parallel and central meridian intersect each other at right angles. As a result the shape is distorted as one moves away from the standard parallel and the central meridian.

Construction :

The graphical construction is similar to that of the simple conic with one standard parallel except that in this case each parallel is truly divided. The intervals along the parallels can be found out from fig. 50.

The measurements for mathematical construction can be had from the following formulae :

Radius of the standard parallel = R cos. lat.

Interval along the central meridian $= 2\,\pi\,R\,\dfrac{\text{interval}}{360}$

Interval along the parallels $= 2\,\pi\,R\cos.\text{lat.}\ \dfrac{\text{interval}}{360}$

= interval along the central meridian × cos. lat.

Properties and uses :

The parallels are arcs of concentric circle ; they are equi-spaced and truly divided. Distances along them are true, but they are not true between them except along the central meridian. Except for the central meridian, all meridians are curved lines. The central meridian intersects the parallels at right angles. Away from the centre of the projection intersections become

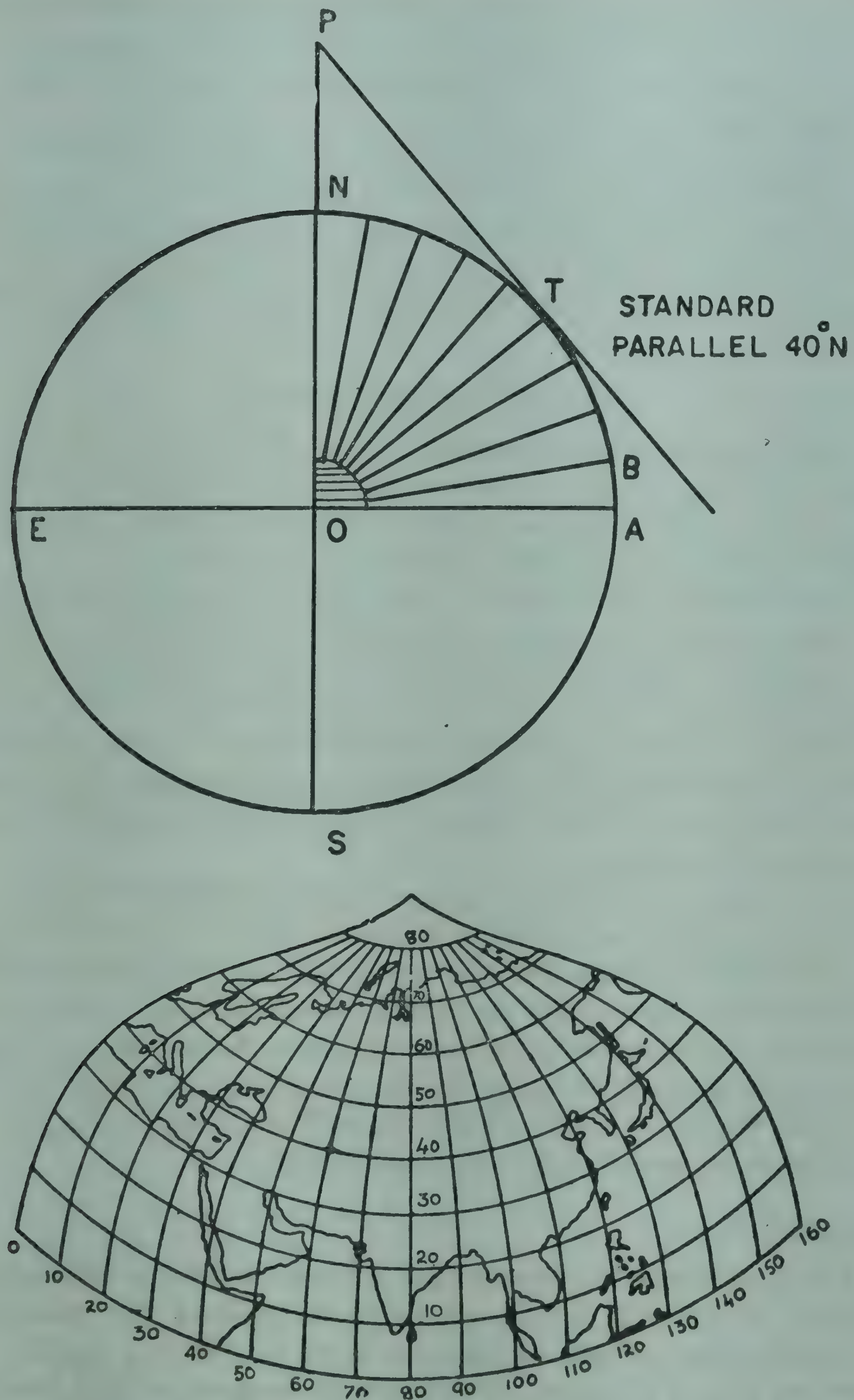


Figure 50: Bonne's Projection

progressively oblique, and therefore the shapes of areas represented become distorted. It is not an orthomorphic projection. Each quadrangle of the projection is equal in area to its corresponding quadrangle on the globe made on the same scale.

This projection is often used to represent continents like Europe, North America and Australia. It is less suited for representing Asia because large chunks of areas falling on the margins away from the central meridian get distorted in shape (fig. 50). It is not suitable for Africa. It has been used in topographic mapping by several European countries like Netherlands, Belgium and Switzerland.

POLYCONIC PROJECTION

This projection is also a modified version of the simple conic projection. The very name of the projection implies the concept of using several cones at the same time. It was developed by Prof. Ferdinand Hassler, the first superintendent of the Coast and Geodetic Survey of the U.S.A.

In the simple conic projection, the radius of the standard parallel is equal to the radius of the corresponding parallel on the globe of the same scale. Meridians intersect the parallels at right angles. It is, therefore, possible to fit maps of adjacent areas lying east and west of each other. But in the absence of bounding parallels of constant length (the length of parallel will depend upon the selected standard parallel) maps of areas north or south of one another cannot be fitted together. The polyconic projection is a device to minimise this drawback.

In the construction of this projection it is presumed that there are as many cones covering a globe as parallels to be drawn. Each of these cones is tangent to its corresponding latitude, thereby making each parallel a standard parallel. The representation along all the parallels is, therefore, correct. This projection divides the map surface into a number of east-west running belts. These belts fit each other only along the central meridian and hence an element of error enters as one moves away from the central meridian. Only along the central meridian the areas as well as the shapes are correct.

Construction :

The construction of this projection is similar to that of the simple conic projection. In the circle (or its quadrant) representing the reduced earth, draw tangents at the latitudes as shown in figure 51. Draw a straight line to represent the central meridian. With respective tangents as radii, the parallels are drawn through the equally spaced points marked on the central meridian.

The arcs of circle so drawn are, however, not concentric. In this case, instead of starting from the appex, we start from the points marked on the central meridian. Fix the pencil-bearing hand of the compass on a point marked on the central meridian and let the needle of the compass fall anywhere on the central meridian in the direction of the pole. Non-concentric arcs are thus drawn to represent the parallels. The intervals to be marked on the parallels can be determined in the same way as in the case of the Bonne's Projection.

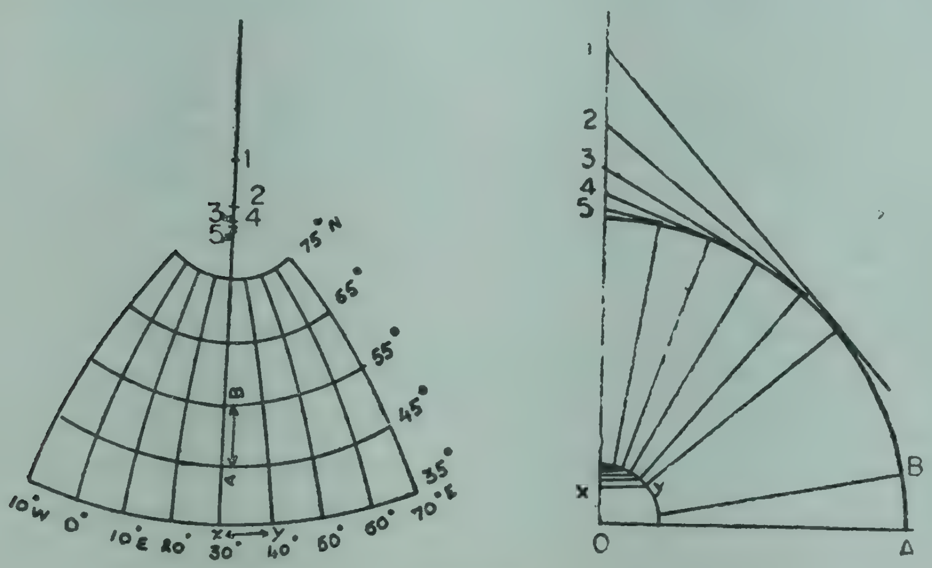


Figure 51 : Polyconic projection.

For mathematical construction, following formulae can be used :

Radii of various parallels = R cot. lat.

Intervals along the central meridian $= 2\pi R \dfrac{\text{Interval}}{360}$

Intervals along the parallels $= 2\pi R \cos.\text{lat} \dfrac{\text{Interval}}{360}$

= interval along the central meridian × cos. lat.

Properties and uses :

In this projection all the parallels are treated as standard parallels and they are not arcs of concentric circles. The equator is shown as a straight line. The parallels are equi-spaced along the central meridian but they diverge away from it. The scale is true along every parallel. The central meridian is also truly divided and hence the scale is true along it. The other meridians are curves diverging toward the equator. The meridians, except the central meridian, do not intersect the parallels at right angles but the obliqueness is less than that in the Bonne's Projection. The scale is not true along the meridians except the central meridian. The projection is neither equal area nor orthomorphic. Both these properties are, however, found near the central meridian.

The projection is not suited for representing large areas. It is useful in representing areas on small sheets designed to fit together on their northern and southern ends. Areas with large latitudinal but limited longitudinal extent in the middle latitudes can be shown satisfactorily on this projection.

INTERNATIONAL MAP PROJECTION

This projection is a modified form of Polyconic projection and is suited for world coverage on 1 : 1000,000 scale. The idea of preparing 1 : 1 m sheets to cover the whole world on a unified network was first advanced by Prof. Penk at the International Geographical Congress held at Berne in 1891. After a long controversy the proposal was ultimately accepted by the International Map Committee of the International Geographical Union in 1909. The committee recommended that modified Polyconic projection should be adopted for the purpose.

The purpose of this projection is to facilitate the preparation of a map of the world in sheets which would fit together on all the sides. This is achieved by making certain modifications in the Polyconic projection. The first modification makes the curved meridians of the Polyconic projection straight. This enables the sheets to fit together along the meridians if drawn on the same scale. Parallels are drawn true to scale, as in the Polyconic projection. This enables the sheets to fit along the parallels too (fig. 52). The second modification consists of the drawing of the central meridians. In the Polyconic projection, only one central meridian is drawn. In this projection, there are two other meridians, one on either side of the central meridian, which are drawn true to scale. The central meridian is smaller than its true length. The other two meridians are true to scale. These meridians are 2° east and west of the central meridian between 60°N and S and 4° east and west of the central meridian between 60° and 88° N. and S. This arrangements makes the exaggeration smaller and better distributed than in the Polyconic Projection.

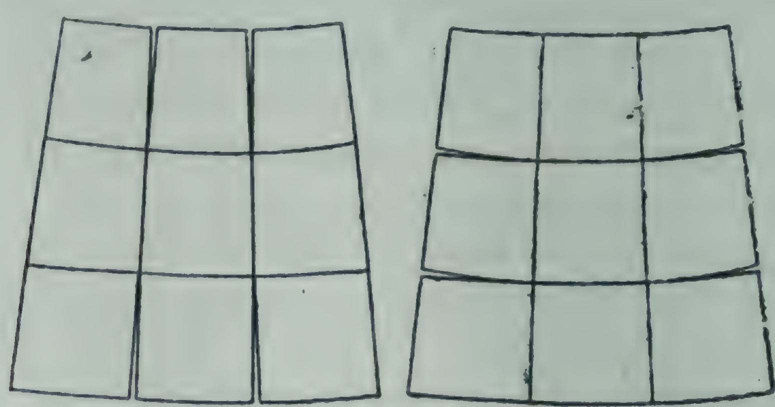


Figure 52: Fit of modified polyconic sheets of International Map of the world.

This projection is drawn on a scale of 1 : 1 million. Each sheet covers 4° latitudes and 6° longitudes between 60° N and S and then 4° latitude and 12° longitude between 60° and 88° N and S. The two polar areas are represented by two circular sheets each having a diameter of 4° latitude. The sheets falling within 60° latitude number 1800, and those within 60° and 88° number 420. With two polar sheets, they total up to 2222 sheets.

On this projection errors do not exceed one hundredth of an inch at any place on the map. This is because of the better distribution of the error as well as the accuracy.

Construction :

The construction of this projection involves the use of the following two tables. The first table gives the corrected lengths between intervals of 4° latitudes. The second table gives the x and y coordinates of the points of intersection of parallels and meridians east and west of the central meridian.

Take the corrected length of the relevant meridian from table 2 and draw a vertical line. Take the coordinates of the top and bottom parallels east and west of the central meridian from table 3 and join them to get the two parallels. Join the coordinates on two parallels to get the six straight line meridians. Divide all the meridians into four equal parts to get the remaining parallels.

Table 2 : *Length of Central Meridian in International Projection in Millimeters*

Latitude	Natural Length	Corrected Length
0° to 4°	442.27	442.00
4° to 8°	442.31	442.04
8° to 12°	442.40	442.14
12° to 16°	442.53	442.28
16° to 20°	442.69	442.45
20° to 24°	442.90	442.67
24° to 28°	443.13	442.91
28° to 32°	443.39	443.19
32° to 36°	443.68	443.50
36° to 40°	443.98	443.81
40° to 44°	444.29	444.14
44° to 48°	444.60	444.47
48° to 52°	444.92	444.81
52° to 56°	445.22	445.13
56° to 60°	445.52	445.44

Table 3: *Co-ordinates of intersection of parallels and meridians in International Projection in Millimeters*

Latitude	Co-ordinates	Longitude from Central meridian		
		1°	2°	3°
0°	x	111.32	222.64	333.96
	y	0.00	0.00	0.00
4°	x	111.05	222.10	333.16
	y	0.07	0.27	0.61
8°	x	110.25	220.49	330.74
	y	0.13	0.54	1.21
12°	x	108.91	217.81	326.73
	y	0.20	0.79	1.78
16°	x	107.04	214.08	321.13
	y	0.26	1.03	2.32
20°	x	104.65	209.31	313.98
	y	0.31	1.25	2.81
24°	x	101.76	203.52	305.31
	y	0.36	1.45	3.25
28°	x	98.37	196.75	295.25
	y	0.40	1.61	3.63
32°	x	94.50	189.01	283.56
	y	0.44	1.75	3.93
36°	x	90.17	180.36	270.59
	y	0.46	1.85	4.15
40°	x	85.40	170.82	256.29
	y	0.48	1.92	4.31
44°	x	80.21	160.45	240.73
	y	0.49	1.95	4.38
48°	x	74.63	149.29	224.00
	y	0.48	1.94	4.36
52°	x	68.69	137.40	206.16
	y	0.47	1.89	4.25
56°	x	62.40	124.83	187.31
	y	0.45	1.81	4.06
60°	x	55.81	111.64	167.52
	y	0.42	1.69	3.80

Properties and uses:

It is neither an equal area nor an orthomorphic projection. Both these properties have been sacrificed to make the adjoining sheets fit together. Each parallel is treated as a standard parallel ; it is curved and is plotted according to its corrected length. Meridians are straight lines. The parallels intersect the central meridian at right angles ; they intersect the other meridians at slightly oblique angles. The two meridians on either side of the central meridian are drawn correct to scale. Distances along the bounding meridians are slightly longer, whereas along the other meridians slightly shorter.

PERSPECTIVE CYLINDRICAL PROJECTION

This projection is also known as natural or true Cylindrical projection. A globe is presumed to be enclosed in a developable cylinder. Light, placed at the centre of the globe, is supposed to cast the image of the graticules of the transparent globe on the cylinder.

Construction :

Draw a circle as per scale. Produce the equatorial diameter to the extent of 2π R. This produced line will be the equator of the projection. Draw two perpendiculars with half the length of the equator on either side of equator. One of these perpendiculars is tangent to the circle. Radii representing the angles of various latitudes are then drawn from the centre of the circle and produced to meet the tangent line as shown in figure 53. From the points of intersection draw lines parallel to the equator. Divide the equator into desired number of divisions to get the meridians.

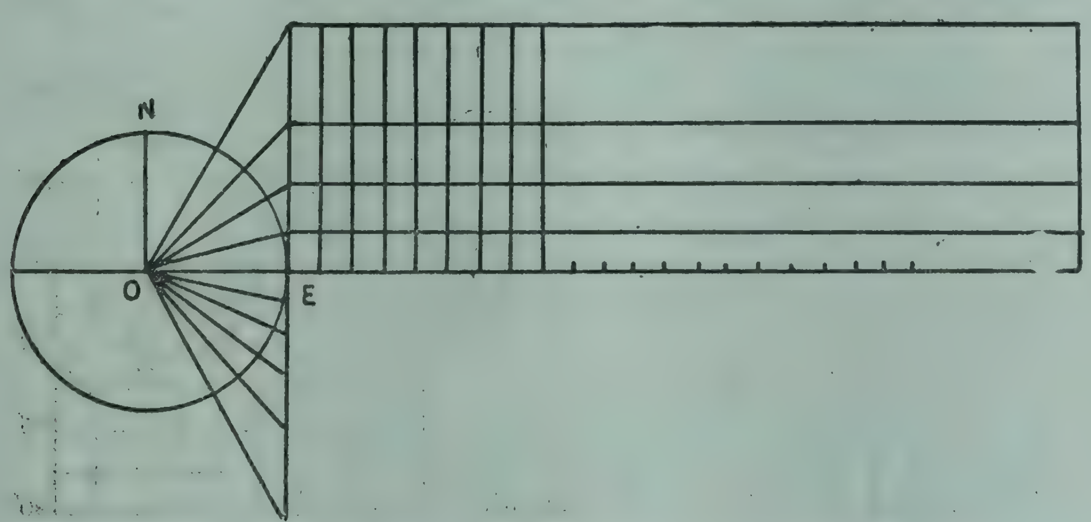


Figure : 53 Perspective Cylindrical Projection.

Properties and uses :

In this projection, the parallels and the meridians are drawn as straight lines cutting each other at right angles. The meridians are equi-spaced but the intervals between parallels increase toward the poles. All the parallels are equal in length. Both the east-west and north-south scales are increasingly exaggerated but the exaggeration is not the same in both the directions. Distances are correctly represented along the equator. This projection is rarely used as the exaggeration of area and shape is too much and only a narrow strip along the equator gives tolerable results.

SIMPLE CYLINDRICAL PROJECTION

To avoid the defects of the perspective cylindrical projection, a number of non-perspective cylindrical projections have been developed. One of these is the simple cylindrical projection. On this projection, the meridians are drawn true to scale. The meridians as well as the parallels are equally spaced. They cut each other at right angles to form a network of squares.

Construction :

For graphical construction, draw a circle with the given reduced earth radius. The equatorial diameter is extended out equal to the required length of the equator. If a network for world map is to be made, the length of the equator will be $= 2\pi R$. Draw an angle showing the latitude of the given interval and making an arc at the circumference of the circle. This arc distance is the interval along the parallels as well as the meridians. Mark these intervals along the equator and the two perpendiculars erected at the two ends of the equator. Join the corresponding points marked on the perpendiculars to get the parallels. Draw meridians through the points marked on the equator (fig. 54).

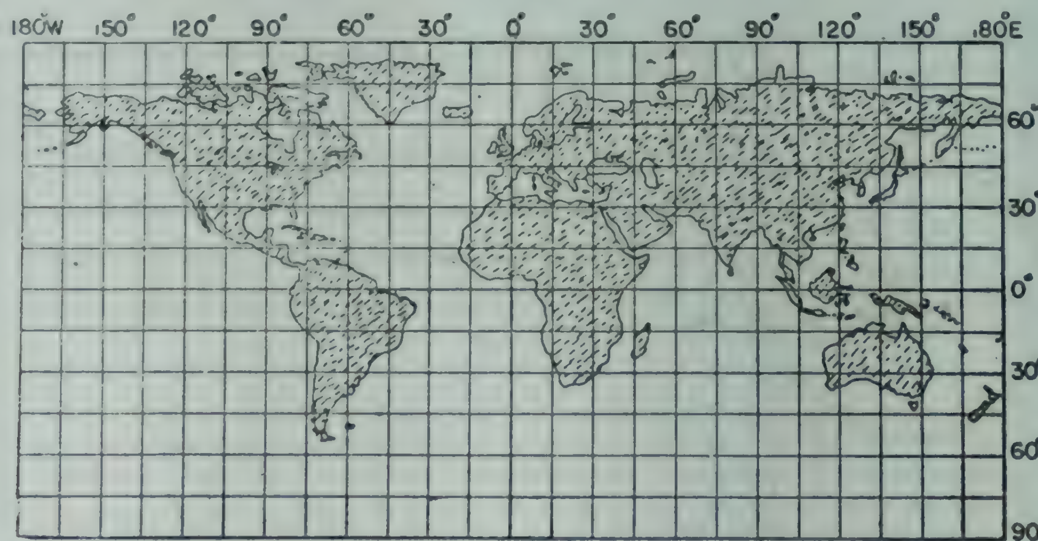


Figure 54: Simple Cylindrical Projection.

For mathematical construction, the following formula can be adopted. Draw the eqautor equal to $2 \pi R$. The length of the interval along the equator and the meridians $= 2 \pi R \frac{\text{interval}}{360}$.

Properties and uses:

The latitudes are drawn parallel to the equator. As a result the scale is exaggerated at increasing rate away from the equator, so much so that the pole which is a point is represented by a line equal to the equator. The meridians are straight lines, perpendicular to the equator and parallel to each other. The parallels and meridians intersect each other at right angles, and form a series of squares.

This projection is not useful for representing areas in the higher latitudes. It is neither an equal area nor an orthomorphic projection. It can be used for areas which extend along or near the equator as Africa and South-America.

EQUAL AREA OR LABERT'S CYLINDRICAL PROJECTION

To represent the areas correctly, the simple cylindrical projection has been modified to get this projection. It is so designed that the areas of the respective zones are equal to areas of their counterparts on the globe. The shape of the area represented gets exaggerated.

Construction:

The procedure for the construction is illustrated in fig. 55. All that is needed is to draw a circle with the given radius and the equator equal to $2 \pi R$. The equator is divided into required number of parts ($360 \div$ interval). Perpendiculars are drawn to represent the meridians. Lines parallel to the equator are drawn from the points where the radii of latitudes touch the circumference of the circle.

For mathematical construction, the following formulae may be used:

Length of the equator $= 2 \pi R$

Intervals along the equator $= 2 \pi R \frac{\text{Interval}}{360}$

Distances of parallels from the equator $= R \sin \text{lat.}$

Properties and uses:

This is an equal area projection because the exaggeration in areas caused by the increasing length of the parallels toward the pole is equalized by the decreasing distances between the parallels. The scale is, however, correct only along the equator. The parallels and the meridians intersect each other at right

angles. The projection is not orthomorphic. The above deficiencies render it unsuitable for areas which extend to higher latitudes. Africa can be shown on this projection suitably as the equator almost cuts it into two halves.

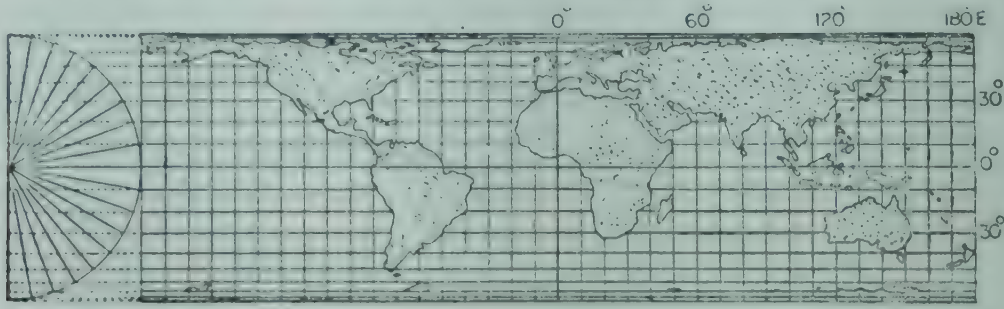


Figure 55: Equal Area or Labert's cylindrical projection.

GALL'S PROJECTION

Gall's projection is an improved version of cylindrical projections discussed so far. In this projection the cylinder is assumed to cut across the globe at 45° N and S i.e. halfway between the equator and the poles (fig. 56). The length of the equator is equal to the length of the latitude along which the cylinder cuts the globe. Thereupon, it is given a perspective effect by supposing the light being placed steriographically (at the opposite end of the equator).

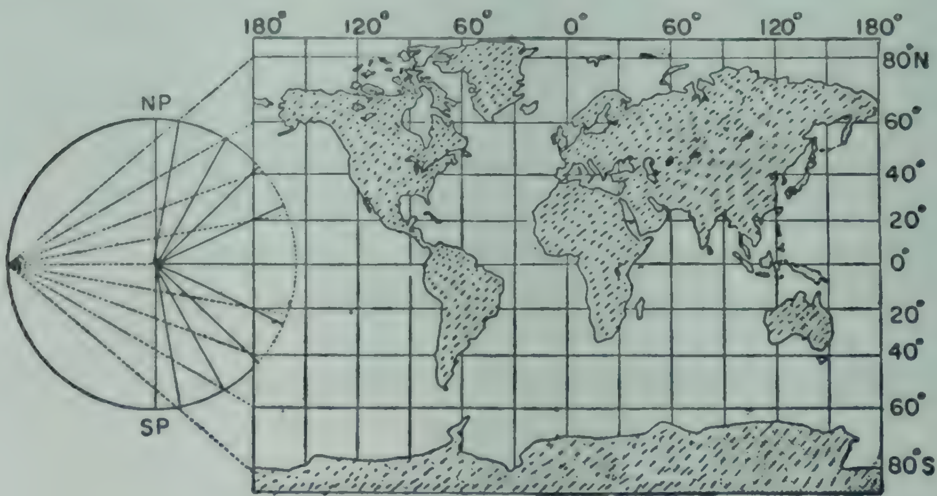


Figure 56: Gall's projection.

Construction:

Draw a circle with the given radius of the reduced earth. Draw radii for latitudes from the centre of the circle to meet the circumference of the circle. Through the points marked by radii of 45° N and S, draw a vertical line to represent one of the sides of the cylinder. Now if the light is placed at the opposite end of the circle the points on the circumference of the circle will

be reflected on the side of the cylinder. These reflected points serve as the starting points for the parallels which are drawn parallel to the equator. The length of the equator and hence, of all the parallels is equal to $2\pi R \cos. 45°$. Divide the equator into required parts and draw perpendiculars to get the projection as illustrated in figure 56.

For mathematical construction, the following calculations will be required :

Length of the equator $= 2\pi R \cos. 45°$

Interval along the equator $= 2\pi R \cos 45° \frac{\text{interval}}{360}$

Distances between the equator and the parallels $= 1.7071 R \tan. \frac{\text{lat}}{2}$.

Properties and uses :

It differs from other cylindrical projections in the sense that only the parallels of 45° N and S are drawn true to scale. As a result of this the east-west scale is shortened between these two parallels and exaggerated between 45° and 90° N and S. The meridians are equi-spaced but not correctly divided. Parallels are not equi-spaced ; they get closer toward the equator between 45° N and S and farther apart toward the poles between 45° and 90° N and S. It is neither an equivalent nor an orthomorphic projection. Because of the lessened distortion in the higher latitudes it is often preferred for world maps.

MERCATOR'S PROJECTION

This projection was developed by Gerhard Kramer, a Flemish cartographer (1512-1594) in 1569. It was later modified and improved by Edward Wright a British cartographer in 1599 in the form we have it today. This projection has the property of showing correct directions by straight lines. As a result, it is very useful for navigational purposes. There were four main reasons for its early popularity : (1) Britian being the greatest maritime power and shipping being the chief mode of international transportation during the 19th century, its wide use was inevitable; (2) on this projection the major portions of the then British empire got exaggerated areal coverage giving the impression to the average map reader that the British islands, and its middle latitude colonies were considerably large. It is interesting to note in this regard that on this projection India does not appear to be more than 5 times the size of the British Isles and Greenland appears to be larger than the whole of South America ; (3) the countries of the old world under the political control of the European nations were shown relatively small to belittle their importance and (4) the shapes of countries are well maintained.

This projection has two outstanding features. These are (1) orthomorphism and (2) true direction. Being an orthomorphic projection small areas represented on this projection maintain their shape accurately. This is achieved by distorting the length and the breadth at the same rate.

As in most other cylindrical projections, in this projections also, all the parallels are equal to the equator. This projection differs from other cylindrical projection in that the distances between the successive parallels increase at the same rate at which the distances between meridians increase toward the poles. As a result the amount of exaggeration of scale both north-south and east-west is the same at any given point (fig. 57).

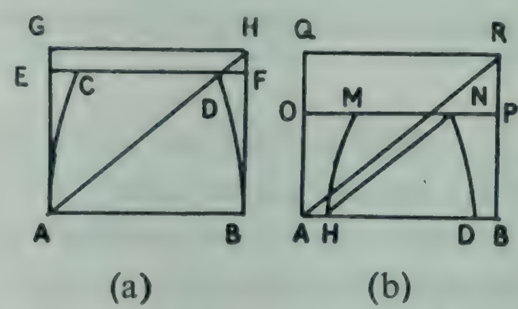


Figure 57: How directions are maintained on Mercator's projection.

In fig. 57 (a) AB is a part of the equator and CD a part of a corresponding parallel. CD has been increased in length east-west to get EF = AB. But EF has also been shifted simultaneously to the position of GH. Here the amount of north-south expansion is of the same order as the east-west expansion. As a result the directions AD and AH remain the same. In figure 57 (b) HD and MN are any two parallels. Both the lines have been increased in length to equal the equator, because in all cylindrical projections the parallels are equal. To keep up with the increase in the length of the two parallels the interval between the two has also been increased, so that MN is represented by QR and not OP. Now the figure MHDN has assumed the shape of figure QABR. In this figure the direction of R from A is the same as that of N from H.

Construction:

Determine the length of the equator with the help of the usual formula of equator being $= 2\pi R$. The distances of other parallels from the equator can be found out as $= 2.3\ R \log. \tan\left(45 + \frac{\text{lat}}{2}\right)$. So that the interval between the equator and 20° N or S (with $R = 1''$) $= 2.3 \times 1 \times .1548 = 356''$. This can also be found out with the help of table 4.

Table 4: *Distances from equator in terms of R in Mercator's Projection*

5°	.087 R
10	.175 R
15	.265 R
20	.356 R
25	.450 R
30	.549 R
35	.652 R
40	.763 R
45	.880 R
50	1.011 R
55	1.153 R
60	1.317 R
65	1.505 R
70	1.736 R
75	2.025 R
80	2.437 R
85	3.132 R

The meridians are obtained by drawing perpendiculars from equally spaced points marked on the equator, as is the case with other cylindrical projection (fig. 58).

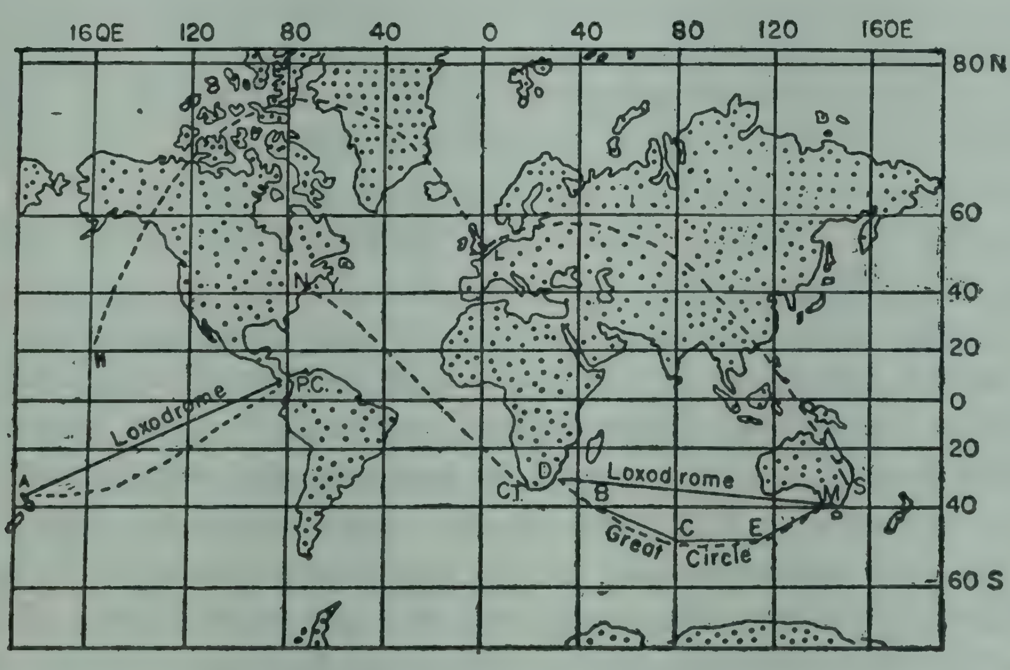


Figure 58 : Mercator's Projection.

Properties and uses :

This is perhaps the best known of all projections mainly because most of the atlases and maps still use it for the portrayal of the world as whole. As already noted it has certain merits, but it has also been responsible for giving a distorted picture of the world to the average map user. Nevertheless, this projection continues to be in use.

Owing to the convergence of the meridians of the globe at the poles, the shortest distance between any two points lying on the same parallel but not on the equator, is not along the parallel of latitude on which the points are situated, but is to the north of that latitude in the northern hemisphere, and to the south in the southern hemisphere. This will be true even in cases of those points which do not lie on the same parallel but are situated east and west of each other. This shortest distances is an arc of a circle and that the completion of the circle gives us a great circle. We, therefore, find that the shortest distance between any two points on the earth's surface is along the arc of the great circle passing through them. The navigators, therefore, follow the great circle routes.

If a sailor has to follow a great circle, other than the equator or one of the meridians, he will have to change directions at every bit of the distance he sails. This will be necessary because great circles are not shown by a straight line on this projection. As against this on the Gnomonic chart, which we propose to discuss in a subsequent section of this chapter, the shortest distance between any two points is given by a straight line joining the two points. This drawback in the Mercator's projection is amply compensated by the fact that a straight line joining any two points on this projection gives a constant bearing i.e. it cuts all the meridians and the parallels through which it passes at the same angle. This line is called *Loxodrome* or *Rhumb line*. This amounts to saying that to reach a given point, all that a navigator has to do is to follow a single bearing all through his course. This naturally gives considerable advantage to the navigator.

We have seen that there are two factors which make the job of a navigator easier. The first is the great circle route and the second is the *Rhumb line* or *Loxodrome*. Unfortunately the arcs of great circles and the Loxodromes joining any two points do not coincide with each other on the Mercator's projection. Ways and means have, therefore, been found to combine the two properties and get the maximum advantage. This has been done by dividing the arc of the great circle into conveient number of sectors as shown in figure 58. These sectors are connected by straight lines. And since any straight line joining any two points on this projection is a loxodrome,

these sectoral lines become a set of loxodromes passing close to the arc of the great circle route. By using these loxodromes, the navigator has to change his directions at only a few places and yet he goes through the shortest route. This is the great merit of Mercator's projection and the reason why it is used so widely by the navigators.

The Mercator's chart is superior to the gnomonic chart in several ways. In the former straight lines are lines of constant bearining, whereas in the latter they are lines giving the shortest distances. To many the latter may seem to be a more useful property, but it is not so because a gnomonic projection has excessive exaggeration away from the centre of the projection. Although poles cannot be shown on the Mercator projection, it does not matter much because polar areas are not so important for maritime activities. Moreover, it is not possible to map the whole world on a gnomonic chart.

ZENITHAL PROJECTIONS

The fundamental assumption underlying the Zenithal projections is that a plane is made tangent to a transparent globe and light is focussed on it from various positions within and outside the globe to produce an image of the parallels and meridians on the plane. In these projections, the directions of all points from the centre of the map projection remain correct. These projections are, therefore, known as azimuthal projections also.

If the light is placed at the centre of the generating globe we get a zenithal projection which is called gnomonic. If the light is placed at a point diametrically opposed to the point where the plane touches the globe, then the projected image gives a steriographic projection. And finally, if the light is placed at infinity to cast parallel rays, we get an orthographic projection. Thus we have three types of perspective zenithal projections. These are :

1. Gnomonic,
2. Steriographic, and
3. Orthographic.

Each of these three types of zenithal projections can be further sub-divided on the basis of the position of the plane surface on the globe. The plane can be placed at three different positions. These are : (1) one of the poles, (2) the equator, and (3) anywhere between the equator and the poles. All the three types of zenithal projections are, therefore, further sub-divided into three sub-types. These are :

1. Polar,
2. Equatorial, and
3. Oblique.

Thus we have nine types of perspective zenithal projections.

PERSPECTIVE ZENITHAL PROJECTIONS

- Gnomonic
  - Polar
  - Equatorial
  - Oblique
- Steriographic
  - Polar
  - Equatorial
  - Oblique
- Orthographic
  - Polar
  - Equatorial
  - Oblique

In addition to these perspective zenithal projections, there are a number of non-perspective zenithal projections. Two of these are given here. These are :

1. Zenithal equi-distant projection ; and
2. Zenithal equal-area projection.

Only polar and equatorial cases are discussed here.

GNOMONIC PROJECTION : (POLAR CASE)

This projection is obtained by casting the shadow of the network of the parallels and meridians on a tangent plane which touches the globe at one of the poles. On this projection a straight line joining any two points gives the shortest distance between those points. In other words the great circles are represented by straight lines.

Construction :

Draw the angular lines for the latitudes to be represented in a circle of a given radius as shown in figure 59. A plane sufrace LP is made tangent to this globe at the pole. To determine the radii of the parallels of the projection produce the angular lines drawn within the circle to meet the plane surface at M, N, O, P, etc. The required radii are LM, MN, NO, OP, etc. Now with L as the centre, draw concentric circle with these radii. Divide the circles into required parts to show the meridians.

For mathematical construction we have to know only the radius of each parallel. This can be done with the help of the formula :

Radius of the parallel = R cot lat.

Properties and uses :

In this projection the parallels are concentric circles ; they are not equi-spaced ; the distance between them increases progressively toward the equator. The meridians are straight lines radiating from the centre. All great circles are shown as straight lines, hence the shortest distance between any two points on the earth can be easily found out on this projection. The distances along

the parallels and the meridians increase away from the centre and hence the areas are exaggerated. The shapes of the areas represented are also distorted as one goes away from the centre.

This projection is suited for showing small areas in the polar regions. The equator can not be shown on this projection.

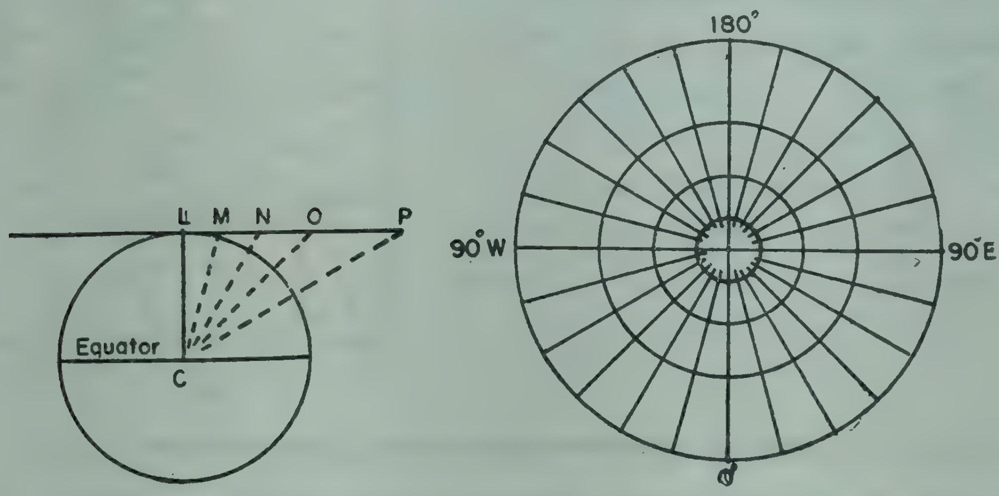
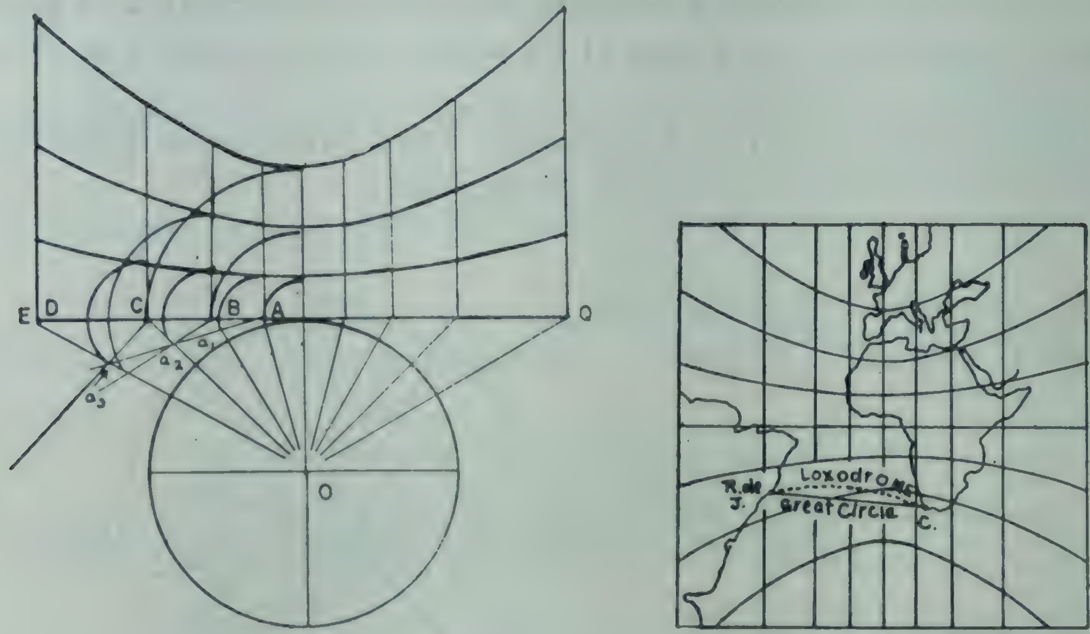


Figure 59 : Gnomonic Projection (Polar case)

GNOMONIC PROJECTION : (EQUATORIAL CASE)

In this case the plane is assumed to be tangent at the equator. Draw a circle with the given radius. Produce the angular lines to the plane surface EQ to get the intervals along the equator as well as the central meridian. To get the intersections of parallels and meridians, draw perpendiculars on angular lines showing the degrees of latitudes at the points these lines meet EQ. Thus a perpendicular Aa is drawn on OA at point A. This perpendicular is intersected by other angular lines like OB, OC, etc. at points a_1, a_2, a_3, etc. Aa_1 is the first interval along its meridian, a_1 a_2 is the second one and so on. After we sub-divide all the meridians this way, we get the network of the Equatorial Gnomonic projection (fig. 60).

In this projection the equator is represented by a straight line. All other parallels are curves. Distances between the parallels increase away from the equator on either side. Meridians are great circles and are projected as straight lines. Distances between the meridians also increase away from the central meridian. Both the area and the shape are distorted away from the centre of the map. It can be used for showing small areas in the equatorial region.



(A) (B)

Figure 60 : Gnomonic projection (Equatorial case)

STERIOGRAPHIC PROJECTION (POLAR CASE)

In the construction of this projection the light is assumed to be placed at a point diametrically opposite the point where the plane is tangent to the globe (fig. 61). After drawing a circle to scale to represent the earth, draw the required angles to show the latitudes. Let the rays emanating from O project these latitudes on the plane surface NF. NA, AB, BC, CD, DE and EF are the required radii for drawing the parallels. With these radii and a common centre N draw concentric circles. The meridians can be drawn with the help of a protractor.

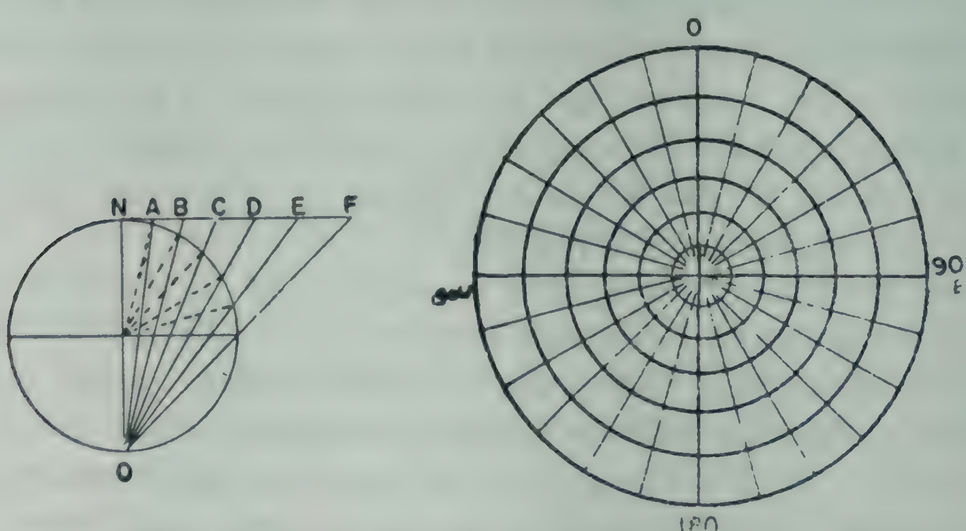


Figure 61 : Steriographic Projection (Polar case)

To determine the radii of the parallels mathematically, the following formula is used.

$$\text{Radius} = 2\,R \tan \frac{90 - \text{lat}}{2}$$

In this projection, the parallels are drawn as concentric circles. They are not equi-distant. The distances between parallels increase away from the centre but the increase is not as rapid as in the case of the gnomonic polar projection. As the equator can also be represented on this projection, it can be used for maps of hemispheres also. The meridians are straight lines radiating from a common centre. The direction from the centre to any point on the projections is correct. As the scales along the meridians increase away from the centre at the same rate at which they increase along the parallels, the shapes of areas shown on this projection are maintained correctly. In other words, it is an orthomorphic projection. Since a circle on the sphere remains a circle on this projection, it is very useful for astronomical purposes.

STERIOGRAPHIC PROJECTION: (EQUATORIAL CASE)

Like its polar version, the equatorial case of this projection is used to represent a hemisphere. The polar case is used to show the northern and southern hemispheres whereas the equatorial case is used to show the eastern and western hemispheres. To construct this projection follow the same procedure as in the polar case to get the intervals along the equator and the central meridian. Intervals along these two are the same.

Draw two straight lines perpendicular to and intersecting each other to represent the equator and the central meridian. Mark the intervals along them (fig. 62). Draw the bounding meridian. With the help of a protractor mark angles of the given interval along the circumference of the circle which is also the bounding meridian. Join the corresponding points (two on the bounding meridian and one on the central meridian) by arcs of circles. To draw an arc of a circle passing through any three points, the following procedure should be adopted. Suppose A, B, and C are the points through which the arc should pass. Join AB and BC and locate their mid-points. From the mid-points, draw perpendiculars which meet at a common point O. $OA = OB = OC$ will be radius of the circle.

For mathematical construction the following procedure is suggested. Draw the bounding meridian (circle) with the given radius. Draw the equatorial and polar axes and produce them outside the circle (fig. 62). As the meridians and parallels are arcs of nonconcentric circles, we have to determine the radii and the centres of these arcs. The formulae for these are :

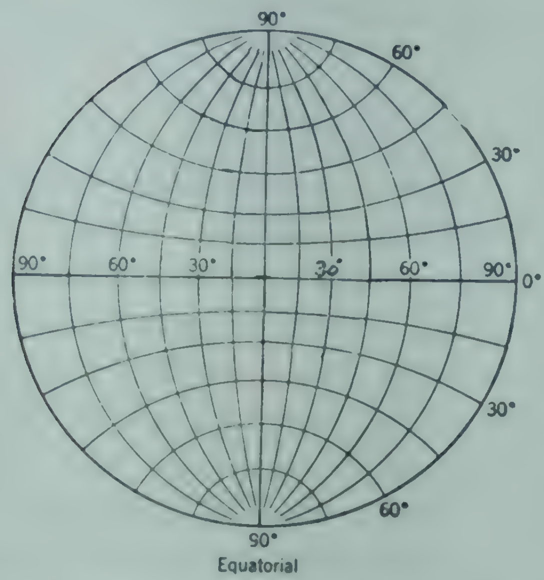


Figure 62: Steriographic Projection (Equatorial case)

With the point of intersection of the polar and the equatorial axes,

Centre of a parallel = 2 R cosec. lat.

Radius of a parallel = 2 R cot. lat.

Centre of a meridian = 2 R cot. long.

Radius of a meridian = 2 R cosec. long.

All the parallels and the meridians excepting the equator and the central meridian are arcs of non-concentric circles. Neither the parallels nor the meridians are equi-spaced. Distances between them increase away from the centre. The projection is commonly used for maps of hemispheres.

ORTHOGRAPHIC PROJECTION: (POLAR CASE)

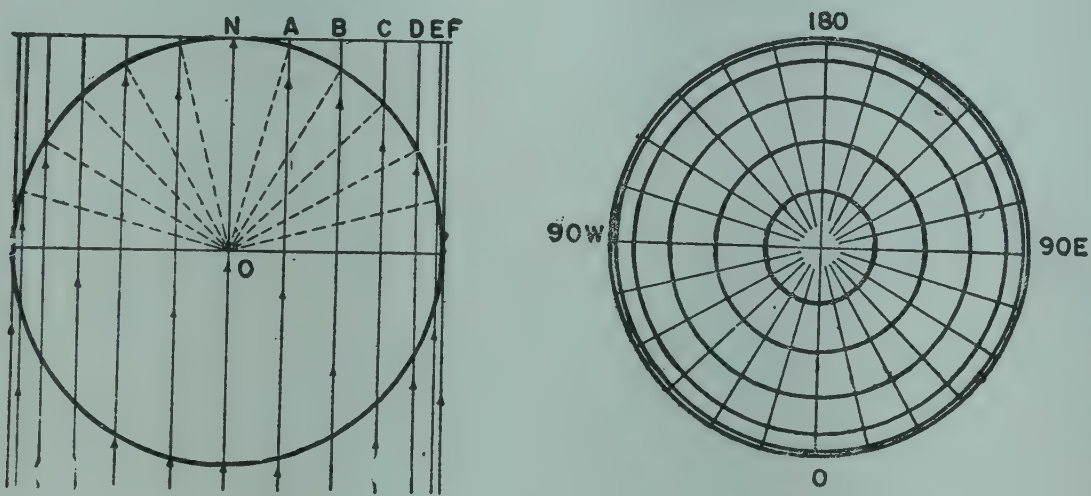
In this projection the light is presumed to be focussed from infinity, so that the rays passing through the globe come parallel to each other. The plane surface touches the globe at the pole. To construct this projection, first, draw a circle with the given radius. Draw angles at given intervals. Draw perpendiculars on the plane surface NF passing through the points where the angular lines intersect the circumference of the circle. NA, AB, BC, CD, DE, and EF are the radii of the parallels. With these radii draw the projection as shown in figure 63.

For mathematical construction the radii of various parallels can be found out by using the formula

Radius of a parallel = R cos. lat.

On this projection the parallels are concentric circles. They are not equi-spaced. The distances between them decrease away from the pole.

Meridians are straight lines radiating from the pole. As is the case with all zenithal projections, the direction from the centre to any other point on this projection also is correct. Scales along the parallels are correct and hence distances along them are correctly represented. This is, however, not the case with respect to the meridians. Because of the excessive shortening of scales along the meridians, both the area and shape are excessively distorted. It is particularly so at places away from the centre of the projection.



(A) (B)

Figure 63 : Orthographic Projection (Polar case)

ORTHOGRAPHIC PROJECTION : (EQUATORIAL CASE)

The construction of the equatorial case is similar to that of the polar case. A circle of a given radius is constructed and intervals along them marked as in the polar case. The meridian are then drawn as ellipses joining the poles and the relevant interval along the equator. The parallels are drawn as straight lines (fig. 64).

Figure 64 : Orthographic Projection (Equatorial case)

ZENITHAL EQUIDISTANT PROJECTION : (POLAR CASE)

This is a non-perspective projection. The parallels are drawn at their true distances from one another. Because of this characteristics, it is called equi-distant projection.

For constructing this projection all that is needed is the true distance between parallels along a meridian. This distance is $= 2\pi R \dfrac{\text{interval.}}{360}$ Having gotten the interval, take a meridian and mark the intervals from the centre. These markings give the radii of various parallels (fig. 65). Draw the meridians as straight lines radiating from the centre.

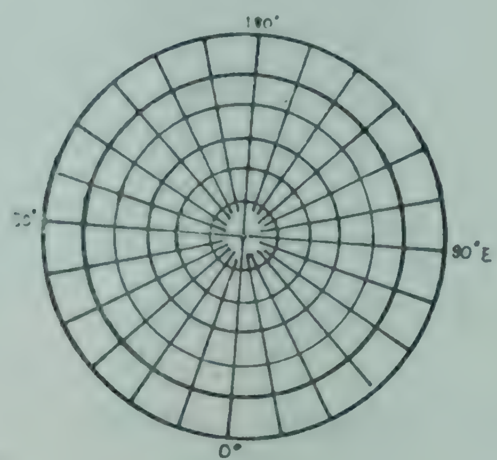


Figure 65 : Zenithal Equidistant Projection (Polar case)

On this projection one of the poles forms the centre of the projection. The parallels are concentric circles equally spaced from one another. Meridians are straight lines. Scales along the meridians are correct. Hence directions as well as distances from the centre to any point along the meridians are correct. The scales along the parallels are not correct and hence the distances along them are exaggerated. The excessive divergence of the meridians outwards distorts the area. It is neither an orthomorphic nor an equal area projection.

This projection can be fruitfully used for a hemisphere if the objective is to show correct distances and directions from the centre of the projection. Large areas cannot be shown satisfactorily. It is generally used for polar areas extending from 90° to 50°, althrough it can be extended to cover the entire globe.

The equatorial case of the projection can also be drawn very easily. The radius of the circle drawn as the bounding meridian of the projection will be 1.57 times that of the reduced earth radius.

ZENITHAL EQUAL AREA PROJECTION: (POLAR CASE)

It is also called Lambert's Azimuthal Equivalent Projection and Lambert's Equal Area Projection. It is also a non-perspective projection. This projection is made equivalent by compensating the increase in scale along parallels with a proportionate decrease in scale along meridians. The area of a zone of the projection is equal to the area of the corresponding zone on the globe.

The radii of various parallels of the projection are found out by joining the pole with the points where lines showing the angles of latitudes cut the circumference of the circle. Meridians are drawn plotted as straight lines (fig. 66).

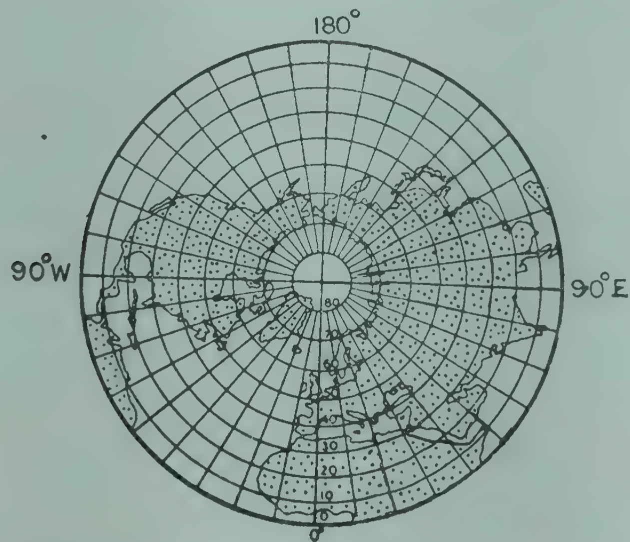


Figure 66 : Zenithal Equal Area Projection (Polar case)

The radii of the parallels can also be found out mathematically. The formula for this is

$$r \text{ (radius)} = 2 \text{ R} \sin \frac{\text{co-lat.}}{2} = 2 \text{ R} \sin \frac{90 - \text{lat.}}{2}$$

On this projection the parallels are drawn as concentric circles, but they are not equi-spaced. The spacing between them decreases outward from the centre. The scale along the parallels is increasingly exaggerated away from the centre. The radial compression of the meridians is proportionate to the enlargement of scale along the parallels. This makes it an equal area projection The directions from the centre are also correct.

ZENITHAL EQUAL AREA PROJECTION: (EQUATORIAL CASE)

For constructing the equatorial case of the projection draw a circle with a radius = 2 R. The distances of various latitudes from the intersection of the polar and equatorial axes can be had from the table given for Mollweide's

projection. The intervals between the intersection of the two axes and various meridians and parallels are the same.

CONVENTIONAL PROJECTIONS

The following conventional projections are discussed here:

1. Globular Projection
2. Mollweide's Projection
3. Interrupted Mollweide's Projection
4. Sinusoidal Projection
5. Interrupted Sinusoidal Projection
6. Hammer's Projection

GLOBULAR PROJECTION

This projection is one of the easiest and most popular ones. On this projection a hemisphere is represented by a circle. The radius of this circle is = 2 R. To show the whole world we need a pair of circles (figure 67).

Figure 67: Globular Projection

Construction:

Draw a circle with the radius = 2 R. Also draw the equator and the central meridian as straight lines intersecting each other at the centre of the

circle. Divide the central meridian and the equator into equal parts. The number of parts will be determined by the interval selected for the projection. Divide the bounding meridians (the circle) also into same number of parts. Join the corresponding points on the central meridian and the bounding meridian on both sides of the equator by arcs of circles. These arcs will form parallels. Similarly join the north and south poles through the various divisions on the equator to get the meridians.

Properties and uses:

The projection is highly arbitrary in matters of cartographic details. The parallels and the meridians (except for the equator and the central meridian) do not intersect each other at right angles. Because of the inequality in scales both along the parallels and meridians, shapes get distorted away from the centre of the projection. As distances between parallels tend to increase away from the central meridian, areas also get distorted toward the margins. It is neither an equal area nor an orthomorphic projection. Nevertheless, it is often used for showing hemispheres in atlases for the simple reason of its simplicity.

MOLLWEIDE'S PROJECTION

Unlike the globular projection, the Mollweide's Projection can represent the whole world within one network. This is an equal area projection and maintains the shapes fairly well in the equatorial, tropical and mid-latitude areas. It is quite a popular projection these days.

Construction:

The network of the Mollweide's projection is drawn in an ellipse the area of which equals the area of the globe. The ellipse of the projection is so drawn that it is double the area of the circle encompassing 90° E and W of the central meridian. First of all draw a circle with the radius = $\sqrt{2}$ R. Now produce the equatorial axis both sides equally so that its total length is four times the radius of the circle. This horizontal line measuring twice the diameter of the circle will represent the equator. The central meridian forms the polar axis of the sphere. Tables 5 and 6 give the intervals along the parallels and the meridians.

Table 5 : *Distance of the parallels from the equator in Mollweide's Projection*

5° Lat.	.0970 R
10°	.1936 R
15°	.2896 R
20°	.3846 R
25°	.4787 R
30°	.5714 R
35°	.6621 R
40°	.7508 R
45°	.8372 R
50°	.9209 R
55°	1.0014 R
60°	1.0783 R
65°	1.1508 R
70°	1.2189 R
75°	1.2814 R
80°	1.3370 R
85°	1.3835 R
90°	1.4142 R

Table 6 : *Intervals along the parallels in Mollweide's Projection*

Lat.	Int.	Lat.	Int.
5°	.9977 × I.E.	50°	.7589 × I.E.
10°	.9906 × I.E.	55°	.7062 × I.E.
15°	.9788 × I.E.	60°	.6471 × I.E.
20°	.9623 × I.E.	65°	.5811 × I.E.
25°	.9410 × I.E.	70°	.5071 × I.E.
30°	.9148 × I.E.	75°	.4232 × I.E.
35°	.8836 × I.E.	80°	.3259 × I.E.
40°	.8474 × I.E.	85°	.2068 × I.E.
45°	.8059 × I.E.	90°	.0000 × I.E.

I.E. = Interval along the Equator.

Divide the equator and the parallels into equal parts. Mark the intervals along the central meridian and draw parallels parallel to the equator through the points marked on the central meridian. Join the corresponding points marked on various parallels, including the equator, to get the meridians (fig. 68).

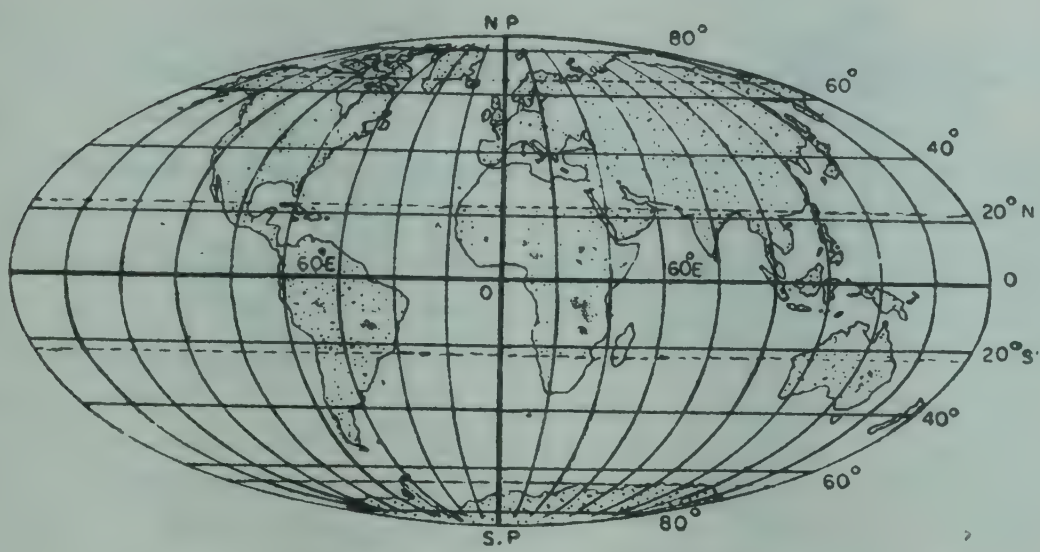


Figure 68: Mollweide's Projection

To determine the length of intervals along various parallels we can use the following formula.

Length of one interval along the equator $= 4\sqrt{2}\,R\ \frac{\text{Interval}}{360}$

Length of one interval along other parallels $= 4\sqrt{2R}$ Cos. y $\frac{\text{Interval}}{360}$

where y = elliptical equivalent of the latitude.

Properties and uses: The parallels are straight lines parallel to the equator. They are not equi-spaced. Except for the central meridian, all meridians are ellipses. The 90° E and W meridians form a circle. This projection is an equal area projection. The scale along the parallels differ from parallel to parallel. The shape of the area shown gets too exaggerated near the margins. It is, therefore, not a conformal or orthomorphic projection.

Being an equal area projection, it is used for showing distribution of various things, specially those which are found in the equatorial, tropical or mid-latitude areas. It represents the areas better than the Sanson—Flamsteed's projection does. It is, therefore, preferable.

INTERRUPTED MOLLWEIDE'S PROJECTION

This projection is a modified form of Mollweide's projection. It was developed by Prof. J. P. Goode in 1916. He called it as homolographic projection. The chief aim of this projection is to minimise the distortion in the shape of marginal areas by selecting a number of central meridians instead of only one central meridian (fig. 69).

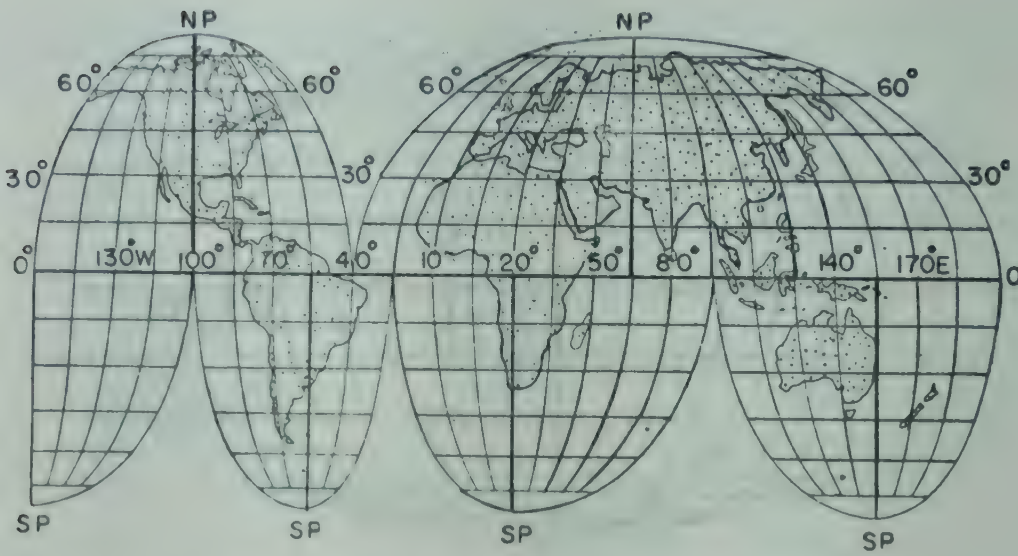


Figure 69: Interrupted Mollweide's Projection

To construct this projection select the meridians to be treated as central meridians and then mark the meridians where the projection has to be interrupted. The selection should be so made that on either side of the equator central meridians and meridians of interruptions alternate. Divide the equator into the required number of divisions. The procedure for division is the same as in the case of the Mollweide's projection.

At the selected meridians, erect perpendiculars to get the central meridians. From the table given for Mollweide's projection, mark the intervals between the parallels along all the central meridians. Draw lines passing through these points and parallel to the equator. Now mark intervals along all the parallels with the help of the table given for mollweide's projection. These intervals need to be marked on both sides of each of the central meridians upto the meridian of interruption. Join the relevant points marked on various parallels to get the other meridians.

While selecting the central meridian and the meridians of interruption, care should be taken to see that the interruptions do not occur along areas which are sought to be given importance in the map. For example, if the objective is to show land areas of the world, the meridians of interruption should occur in the water areas.

SINUSOIDAL PROJECTION

This projection is also known as Sanson - Flamsteed projection or Mercator-Sanson-Flamsteed projection. It is called Sinusoidal because sine curves are used in its construction. It is called Mercator-Sanson-Flamsteed

because it is supposed to have been used by mercator in 1605, by Sanson (a French cartographer) in 1650 and by Flamsteed (a British astronomer) in 1729.

This projection may easily be treated as a special case of Bonnes projection with equator as the standard parallel. The equator is represented as a straight line. Since all other parallels are parallel to the standard parallel, they are also straight lines. The central Meridian and parallels are correctly divided as in the case of the Bonne's projection. It is an equal area projection.

Construction: For the construction of this projection one has to go through the same process as used in the construction of the Bonnes projection. The length of the equator can be found out by the formula $2 \pi R$. The central meridian is half the equator and is drawn perpendicular to it at its mid-point. The divisions along the equator or the central meridian can be found out by the formula $2 \pi R \frac{\text{Interval}}{360}$. Divisions along other parallels can be found out the same way as in the case of Bonnes projection. Through the points dividing the central meridian, draw parallels to the equator. Join the corresponding points on the parallels by smooth curves to get the meridians (fig. 70)

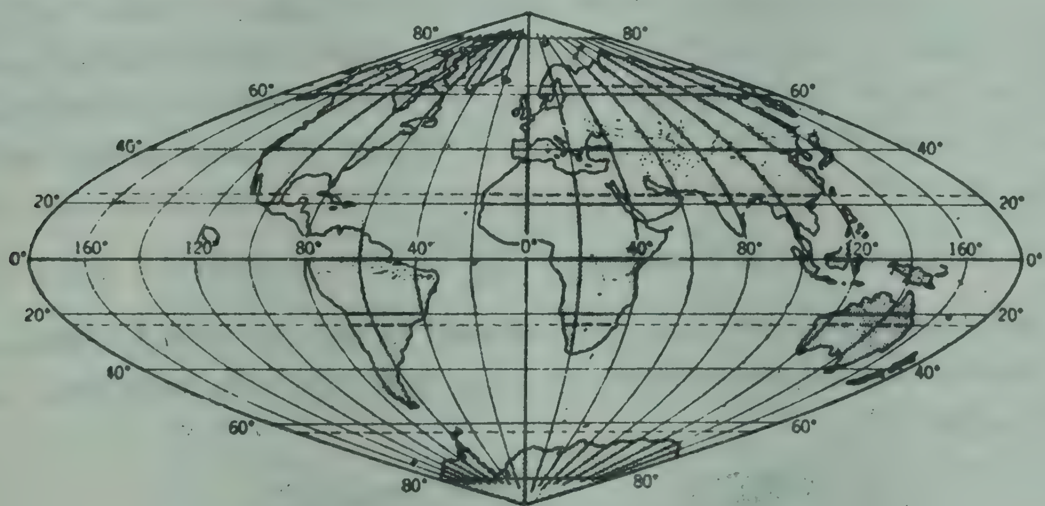


Figure 70: Sinusoidal Projection

For mathematical construction the following formula should be used:

$$\text{Equator} = 2 \pi R$$

$$\text{Central meridian} = \frac{2 \pi R}{2} \text{ or } \pi R$$

$$\text{Interval along the equator and the central meridian} = 2 \pi R \frac{\text{interval}}{360}$$

$$\text{Intervals along other parallels} = \text{Interval along Equator} \times \cos. \text{lat.}$$

Properties and uses : Equator is the standard parallel and is drawn as a straight line. Other parallels are also drawn as straight lines. Parallels are equi-spaced and correctly divided. Except the central meridian all meridians are Sine curves. The scale is true along all parallels and the central meridian. But the scale along other meridians is not correct ; it gets increasingly exaggerated away from the central meridian because of the varying obliquity of the intersections of meridians with parallels.

The projection, being an equal area one, is useful in representing distributional data. It is most suited for continents extending to equatorial regions and middle latitudes such as Australia, Africa, and south America. A world map is not well represented on this projection because the increasing distortion of shape on the margins reduces the legibility of the map.

INTERRUPTED SINUSOIDAL PROJECTION

This projection was also developed by Goode. He had named it as Homolosine projection. Here the aim is to improve the shape of marginal areas which get too distorted on a Sinusoidal projection.

The construction of this projection is easier than that of the interrupted Mollweide's projection. First select the meridians which are to be treated as central meridians and the meridians of interruption. Draw the equator = $2\pi R$. Divide the equator into required divisions. Draw each central meridian equal to one fourth of the equator. Mark intervals along the central meridians. Draw lines parallel to the equator along the points marked on the central meridians to get the parallels. Mark intervals along each of the parallels on both sides of the central meridians. The intervals along the parallels are equal to $2\pi R \cos lat \dfrac{\text{interval}}{360}$. While marking these intervals on the parallels, the interrupted parts should be left unmarked. Draw smooth curves through the relevant points on the equator and the parallels, to get the meridians (fig. 71).

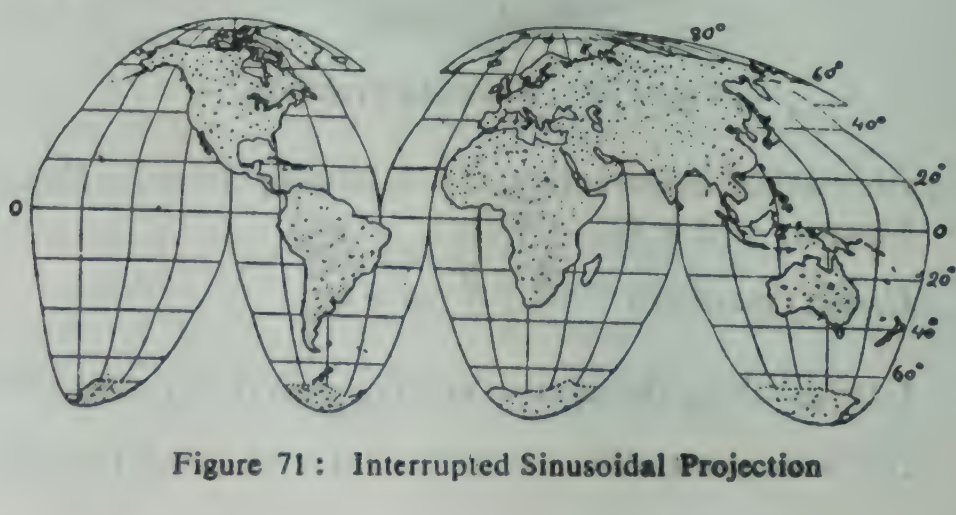


Figure 71 : Interrupted Sinusoidal Projection

HAMMER'S PROJECTION

This projection is often referred to as Aitoff's projection. The Aitoff's projection is not an equal area projection and its graticules are derived from zenithal equi-distant projection. Hammer's projection on the other hand, is an equal area projection and its graticules are derived from zenithal equal area projection. And hence to call it Aitoff's projection is incorrect.

To construct this projection, draw the equator = $2\pi R$. Draw a perpendicular line to divide the equator as well as itself into two equal parts. The full length of this line should be half that of the equator. This line will function as the central meridian. To mark the intervals along the equator and the central meridian, we have to refer to the equatorial case of the zenithal equal area projection. As there is no change in the dimensions of the central meridian, the table used in the zenithal equal area projection (equatorial case) to determine the intervals along the central meridian, can be used in this projection also. In this connection it may be recalled that this table is the same as used for the Mollweide's projection. The equator can also be divided the same way keeping in view that it is double the length of its counterpart in the zenithal equal area projection. The intersections of all other meridians and parallels in the zenithal equal area projection can be determined by treating the equator as the x axis and the central meridian as the y axis, and the intersection of the two as the point of origin. Same measurements can be used to locate the corresponding intersections on the Hammer's projection, if the x axis is doubled. The completed projection is illustrated in fig. 72.

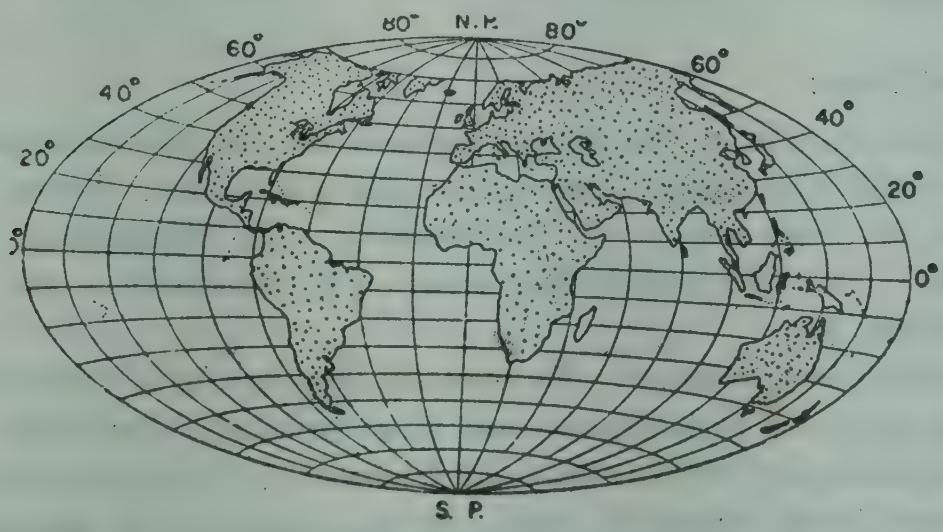


Figure 72: Hammer's Projection

It is an equal area projection and is superior to the Mollweide's projection because the distortions of shapes in the marginal areas are less than in Mollweide's projection.

CHOICE OF PROJECTIONS

In this chapter we have discussed over 25 projections. These, however, by no means exhaust all available and conceivable projections. There can be as many projections as our needs. With the availability of computer services, one can develop hundreds and thousands of projections. But many of these projections will be so complicated and will give such a confused and meaningless outline of the areas we will like to represent, that they will not serve any purpose. It is for this reason that we usually do not make use of more than 50 projections. Some of the most relevant of these important projections have been discussed here.

Projections like any other cartographic technique are only tools to achieve certain ends. They can help fulfill our objectives only if we use them judiciously. The correct use of projections involves their right selection for the purpose in view. We know that there is no projection which can display all the characteristics of a globe. Some of them show areas correctly, some others give correct shapes while still others give correct bearings. Some projections are meant to show only small areas, others are meant to represent larger areas like continents while still others can show up the whole world. There are few other characteristics which individual projections possess. But there is none which possesses all the characteristics simultaneously. A judicious choice of projections, therefore, forms an important step in cartographic processes.

The following are a few guide lines which may be used in the selection of projections.

For a World Map :

General Purpose : For general purposes we can use the equatorial cases of the zenithal equi-distant and equal area projections. Other projections which can be used are : (1) Mollweide's, (2) Hammer's, (3) Simple cylindrical, (4) Cylindrical equal area, (5) Mercator's, (6) Gall's, and (7) Sinusoidal.

Distributional Purposes : To show the distribution of various geographic data, only equal area projections need to be selected. These are cylindrical equal area, sinusoidal, Mollweide's and Hammer's. For showing the distribution of those things which are found in the equatorial or sub-tropical areas cylindrical equal area projection is most suited. On this projection the shape is not too much distorted unless we go beyond 50° N and S of the equator. Equally good, for such purposes, is the Sinusoidal projection. The Hammer's and Mollweide's also can be used. In case the objective is to show the

distribution of something that is found in the mid-latitudes, the cylindrical equal area projection should not be selected. The Hammer's will be the best choice. But the selection of Mollweide's will not be bad. If the distribution has to be shown both in the mid-and-high-latitudes, the obvious choice should go to the Gall's projection.

Navigational purposes: For this purpose the best projection is Mercator's.

For a Continental Map:

General Purposes: The conical projection with two standard parallels is very useful for such purposes. Asia, Australia and North America can be shown well on this projection. For South America and Africa, we may use Sinusoidal projection.

Distributional purposes: To show the distribution of something in a continent the best projection is Bonne's. It is, however, less suited for Asia. The zenithal equal area projection should be the next choice. For Africa Sinusoidal projection can also be fruitfully used. At times Mollweide's and Cylindrical equal area projections are also used.

Navigational purposes: The steriographic projection is often used for these purposes.

For Polar and Sub-Polar Regions:

The best projection to show these areas is the polar steriographic projection. For distributional purposes Zenithal equal area projection should be selected. If correct distances are to be maintained, Zenithal equi-distant projection should be selected.

For Countries and regions:

For general purposes a number of projections are suitable. For polar and sub-polar areas the choice should go to one of the Zenithal projections. For the mid-latitudes, selection would normally be made from one of the conical projections. And for tropical and equatorial areas, a cylindrical projection is likely to be selected.

For the purposes of showing boundaries, railways or roads which pass through a limited latitudinal extent, the selection of the conical projection with one or two standard parallels will be desirable. For example, the US-Canadian boundary will be better shown on a simple conic with one standard parallel. Similarly the Trans-Siberian railway will be better represented on conical projection with two standard parallels. In cases where a strip of land having small longitudinal extent but great latitudinal extent has to be represented

the Zenithal equi-distant or Sinusoidal projections will be most suited. For example, to show the Cape to Cairo railway route, the former will be an ideal choice.

CHAPTER IX

GEODETIC AND PLANE SURVEYING

Surveying is commonly considered to be the science of making measurements needed to locate accurately the details of the earth's surface. Map making in its complete sense involves surveying, for only by surveying can the first accurate map of a given part of the earth's surface be made. The details of the earth's surface change through time. It is only by surveying that the changes, which have occured in the area mapped earlier, can be incorporated accurately and expressed with exactness in the symbolic language of cartography.

Surveying involves extensive field work and elaborate laboratory work. In addition, it involves a good knowledge of the instruments used in the field. Field work includes (1) the measurement of distances and angles, and (2) the preparation of field notes. Field noting consists of the recording of the numerical values, the preparation of sketches of the areas and features surveyed and the explanation of the recorded data.

Surveying can be classified into several types. If we take the purpose of the survey as the criterion, we can have cadastral surveying, topographical surveying, military surveying, geological surveying and so on. But if we consider the accuracy desired and the technique used, we can have (1) Geodetic Surveying, (2) Plane Surveying, (3) Aero-Surveying, (4) Hydrographic Surveying, etc. In this chapter we propose to discuss only geodetic and plane surveying in detail.

GEODETIC SURVEYING

The main purpose of geodetic surveying is to establish a set of control points to which the surveys of lower orders can be tied up subsequently. A control point is merely a spot on the earth whose precise location has been

established. It is a point of reference from which measurements are made to locate other points. Greater the number of control points in a given area, better is the accuracy with which earth features can be mapped.

Before any definitive geodetic surveying covering an extensive area can be done, two critical factors have to be decided. The first factor is the *Datum Point* which is the origin for further comprehensive linear measurements and the other is the *Datum Plane* which establishes the base level for determining elevation. *Datum Point* gives mean earth gravity and the *Datum Plane* the zero elevation.

To understand the importance of these points let us imagine ourselves having been sent to a newly found island to map it and also to establish its position on a world map. Before we can carry out our assigned job we will have to know the longitude and latitude of at least one point. For this we will have to look to the sky and make use of one of the celestial bodies as explained in Chapter VII. To determine the elevation of the selected spot we will have to assume a certain point to be at the zero elevation and then measure the elevation of the proposed control point with respect to the zero level point. We will also determine the position of our point with respect to true or magnetic north.

With the latitude, longitude, elevation and true north established, this spot becomes a point of reference from which other control points can be determined without astronomical observations.

Finding a true *Datum Point* is difficult, because levelling of instruments used in stellar observations is a difficult process. Had the earth been spherical and made of the same rock, a plumb bob would have pointed directly toward the centre of the earth. In most places, however, it does not do so because it is deflected by earth masses like mountains; it actually leans toward the pulling force (See Chapter VIII). Although this pull is known to exist, there is no known way to determine its force and thus to correct the error. We therefore select a station (point) that seems to be least affected by these disturbing influences. It is with reference to this point that the latitudes and the longitudes of other points are determined.

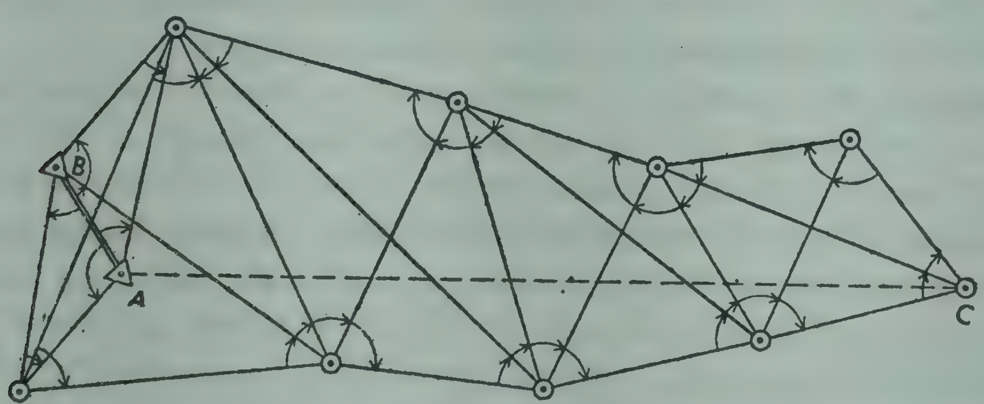
The *Datum Plane* is equally difficult to determine. It is supposed to be the sea level. But we know that sea level is not the same always and everywhere ; it fluctuates. As a convention, it is considered to be an average of the hourly water-height seen for a period of a year or more at a tidal gauge. This has given rise to controversies over the height of such peaks as Mount Everest. The figure depends on where the measurer thinks sea level would be under Mount Everest if a sea were there.

Horizontal and Vertical Controls :

Horizontal Control: Two types of controls are established from the *datum point* and *datum plane*. The first is the horizontal control. It consists of points from which horizontal distances and azimuths can be measured in linear units discounting elevation on the earth's surface. Such points are derived by Triangulation which is a method of establishing control stations by means of a set of mutually connected triangles.

The process of triangulation begins with a reconnaissance survey to select a number of prominent points which constitute the vertices of a set of triangles. These stations are known as trignometrical stations. In between these points, the elevation of several other points is also determined by precise primary horizontal control levelling. These are called Bench Marks. The trignometrical stations are the primary horizontal control stations, and the bench marks the primary vertical control stations.

The next step begins with the determination and measurement of the base line (fig. 73). Base line is selected on a ground which is free from



Known Data : 1. Length of the base line AB. 2. Latitude and Longitude of points A and B. 3. Azimuth of line AB.

Measured Data : Angles to new control points.

Computed Data : 1. Latitude and longitude of point C, and other new points. 2. Length and azimuth of line AC. 3. Length and azimuth of all other lines.

Figure 73 : A simple Triangulation Net (From Geodesy for the Layman).

obstructions to accurate measurements. It is, usually, one of the sides of the first triangle in the triangulation. An object is sighted from both ends of this line. When rays are drawn from each end of the line to the object, we get a triangle. Each angle or azimuth is carefully measured several times and checked by adding the three angles of the triangle to see if they total 180°. Another object is sighted and angular measurements are repeated for the next triangle whose base is formed by a side of the previous triangle. The process is repeated until all triangles of the system are completed. It must be noted that in

triangulation the base line is the only side of a triangle which is measured. All other sides of the triangles are calculated trignometrically. Given a side and two angles of a triangle, the remaining sides and angles can be easily determined. These triangulation stations and Bench Marks are then plotted on a projection selected for the purpose. The topographical and other details are incorporated after the plane and socio-geographic surveys are also completed.

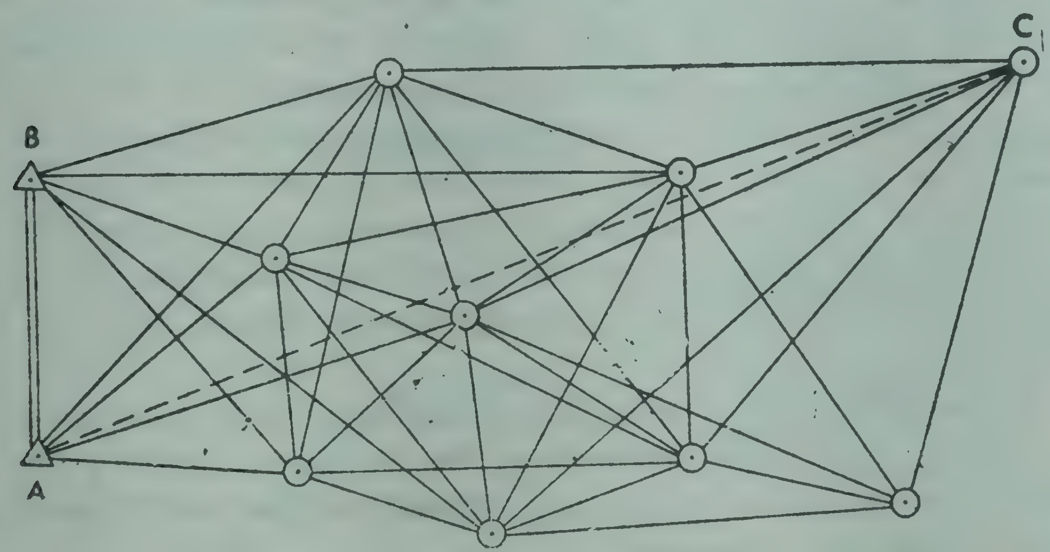
There are four orders of triangulation. The basis for this classification is the degree of accuracy desired. The first order triangulation requires that all triangles must close within 1 second of error and the side lengths must agree to earth measurements within 1 foot in 25,000 ft. (4.5 miles). The second order triangulation permits angular discrepancy of 3 seconds and the horizontal discrepancy of 1 foot in 10,000 feet. The respective figures for third and fourth order triangulations are 5 seconds and more than five seconds and 1 foot in 5,000 feet and 1 foot in 500 feet respectively. The accuracy required in the first and second order triangulations can be had only if geodetic adjustments are made to conform to the earth's ellipsoid and geoid. The triangulations of these two orders are, therefore, the results of geodetic surveys. The third and the fourth order triangulations are used in plane surveying.

Normally, triangulation is carried out by parties of surveyors from pre-planned stations along the arcs of the spherical triangles. If there are obstacles in the way of the parties moving from one station to the other a method known as flare triangulation is employed. Parties locate themselves at all the stations from which measurements have to be taken and magnesium flares are parachuted from air crafts or 'shot' into the air from ships at suitable points between them. Intersections of lines are marked simultaneously at all the stations and thus reasonably accurate 'bridges' are established. This type of connection was established between Norway and Denmark.

In cases where the distances between the points are too long to be intervisible, the above noted methods of triangulation are not helpful. The method of *trilateration* is used in such situations (fig. 74). Trilateration involves the use of radar and other electronic devices. Instruments used in trilateration are geodimeter and tellurometer. In case of the former, light is focussed from one point to the other. The receiving station has a mirror which reflects the light back. The time taken by the light to travel back gives the horizontal distance between the points. Distance between stations lying up to 40 miles apart can be measured this way. Tellurometer is less accurate and is used for shorter distances. It uses radio waves for measuring distances.

In recent years the Shoran and Hiran electronic distance measuring system have also been employed in geodetic surveys. Since lines of about 500

miles can be measured by this system, geodetic triangulation networks can be extended over vast areas in comparatively short periods of time. Surveys of islands and isolated areas can be carried out by these techniques. Shoran is an abbreviated form of 'Short Range Navigation' and Hiran of 'High Precision Range Navigation.' In these systems, radio-waves are sent and received by a plane flying between two points. The time taken by the radio-waves determines the distance of two points from the plane. When the height of the plane is known the horizontal distance between them can also be known.



Known Data : 1. Length of Base line AB. 2. Latitude and longitude of points A and B. 3. Azimuth of line AB.

Measured Data : Length of all triangle sides.

Computed Data : 1. Latitude and longitude of point C, and other new points. 2. Length and azimuth of line AC. 3. Length and azimuth between any two points.

Figure 74 : A simple Trilateration Net (From Geodesy for the Layman)

The celestial techniques of geodetic triangulation involve the use of Solar eclipse, star occultation, moon position, camera method, and observation and tracking of artificial earth satellites. Among these, the last one has proved to be most promising. A satellite is photographed from several observation points. The small angular distances between the images of the satellite and the star background are measured and the direction of the satellite from the observation point is computed. High altitude of the satellite enables us to triangulate across the oceans and determine relative positons between continents.

Vertical Control : Triangulation nets provide the control for locating geographic co-ordinates and for measuring plane distances on the earth or map surface. For the interpretation of terrain, we, however, need vertical control.

This deals with the third dimension. Horizontal control supplies the 'where' 'how big' and the vertical control "how high". Obviously the 'where' must be established first so that an earth feature can be pin-pointed in its proper location. After the spot is located, we want to know someting about its physical form which depends, in part, on how high it is. This is achieved by establishing Vertical control.

Any measuring must begin from somewhere and any relative measuring must be done from a common somewhere. Even though the ocean is far from a high mountain, we can appreciate the height of the mountain only by comparing it with the level of the ocean. Abstract elevations in themselves are difficult to visualize because human mind comprehends only by comparison. The measurement of vertical control, therefore, should logically begin at or be an extension from a common base, *Datum Level* which is the Mean Sea Level at a selected point. Points are measured progressively inland from the Datum Level to complete a network of vertical control that coincides with points of the horizontal triangulation net. The technique of determining the height is called levelling.

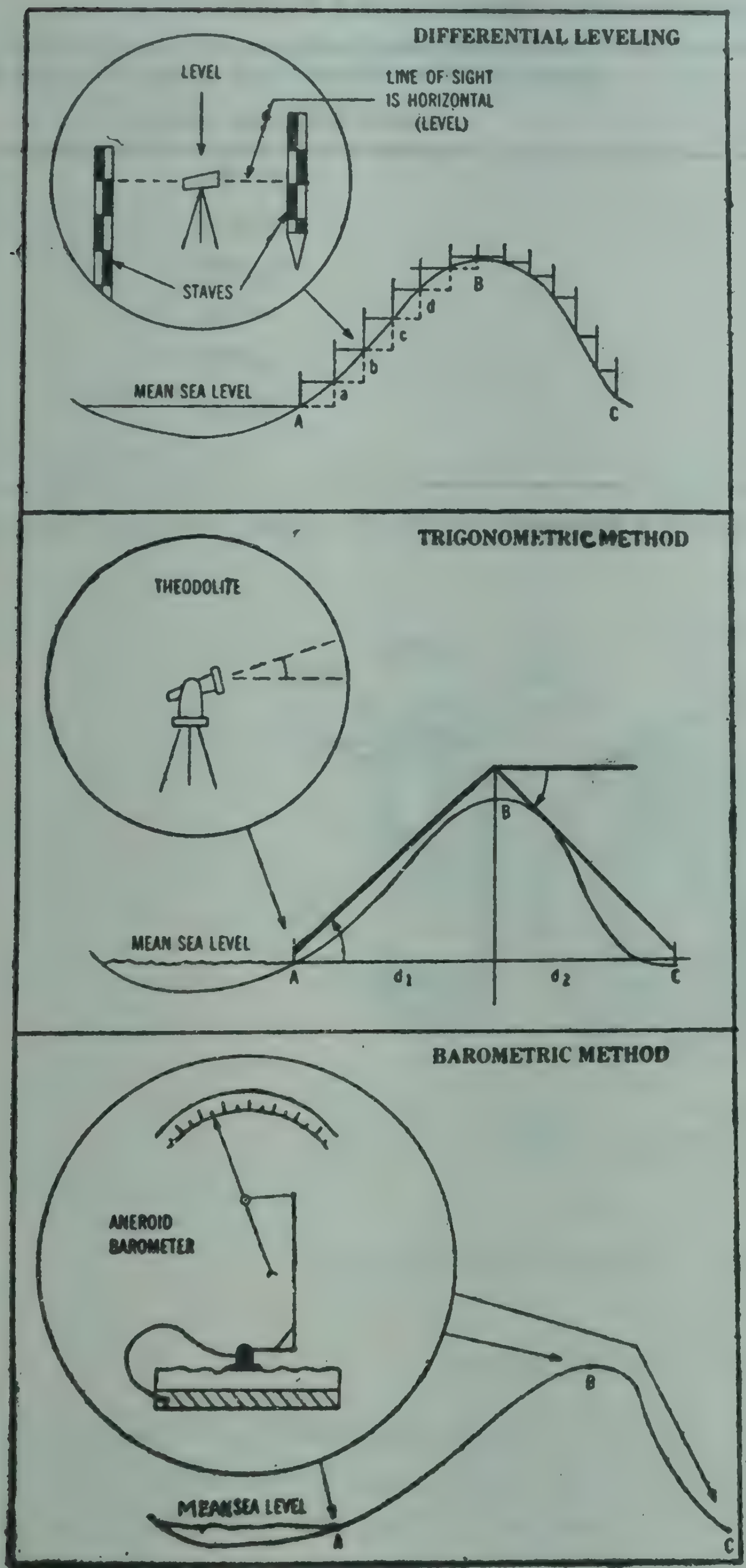
Precise geodetic levelling is used to establish a basic network of vertical control points. With reference to these, the elevation of other points in the area to be surveyed can be determined. There are three levelling techniques in common use (fig. 75). These are :

1. Differential levelling, 2. Trignometric levelling, 3. Barometric levelling.

The differential levelling is the most accurate of the three methods. The instrument used in levelling is called a level. It includes a bubble tube which helps in adjusting the level parallel to the geoid. When properly set, the telescope of the level is in horizontal position. Readings are made on two calibrated staffs held in an upright position ahead of and behind the level. The difference between the readings is the difference in elevation between the two points.

Trignometric levelling involves measuring a vertical angle from a known point with the help of a theodolite and computing the elevation of the point. It is relatively less accurate method although somewhat more economical. It is most suited to mountainous terrain.

Barometric levelling is based on calculations of height from the pressure data. Barometer is an instrument which registers atmospheric pressure. Higher a point lesser the atmospheric pressure. The pressure at the sea level is about 1000 millibars or about 14.5 lbs per sq. inch. At an altitude of 18000 ft. above sea level the pressure is about 500 millibars. Table 7 gives the relationship between height and pressure.



Known Data : Elevation of starting point, A.

Measured Data : Elevation differences, a, b, c, d, etc.

Computed Data : Elevation of B, C, and all other points.

Known Data : Elevation of starting point A. Horizontal distances, d_1, d_2, between points.

Measured Data : All vertical angles.

Computed Data : Elevation of B, C, and all other points.

Known Data : Elevation of starting point A. Gravity and density data.

Measured Data : Air pressure at A, B, C, and all other poins.

Computed Data : Elevation of B, C, and all other points.

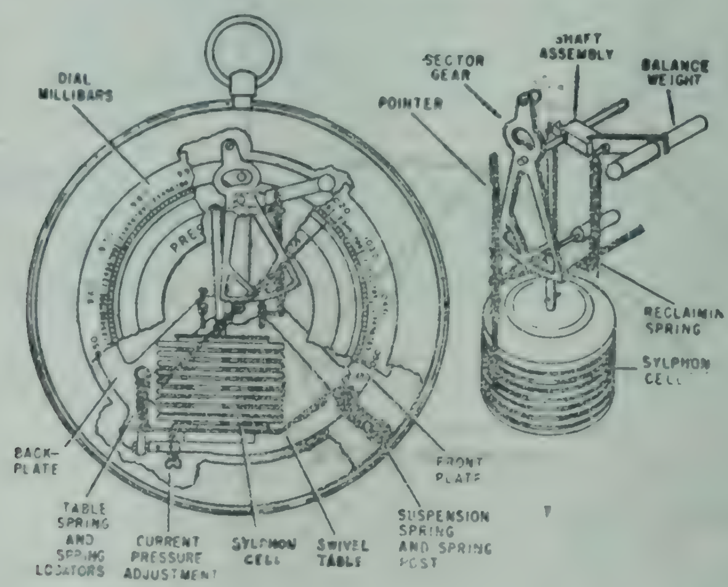
(a)

Figure 75 (a) : Levelling techniques (From Geodesy for the Layman.)

Table 7 : *Relationship between Elevation and Pressure*

Barometric Reading in inches	Height in feet above the point at which water boils at 212° F.
13.970	19,887
15.964	16,412
18.199	12,988
20.690	9,638
23.461	6,354
26.521	3.151
29.921	0

So if the barometer registers a pressure of 20.69 inches, we can assume it to be at a height of 9638 feet.



(b)

Figure 75 (b): Barometer and its parts.

PLANE SURVEYING

Plane surveying, unlike geodetic surveying, assumes the earth to be flat. The reason behind this assumption is that plane surveying is used only for relatively small areas. Usually it is used to fill up the details within the framework of the control points established by geodetic surveying. Plane surveying is also used for such specific purposes as demarcation of various types of boundaries, property lines and allignment of transport lines.

All horizontal and vertical measurements in plane surveying are tied to the measurements given by the trignometrical stations and bench marks.

There are several types of plane surveying. These are :

1. Chain surveying ;
2. Plane-table surveying ;
3. Prismatic compass surveying ;
4. Theodolite surveying ; and
5. Levelling.

CHAIN SURVEYING

For small surveys, one of the methods employed is the so-called Chain surveying. At times it is also referred to as chain and tape surveying. The name 'Chain and tape' is derived from the two main measuring instruments used in this type of survey. This survey is suited to the areas which are relatively level, and where horizontal distances can be measured manually.

INSTRUMENTS

The instruments used in Chain surveying are illustrated in figure 76.

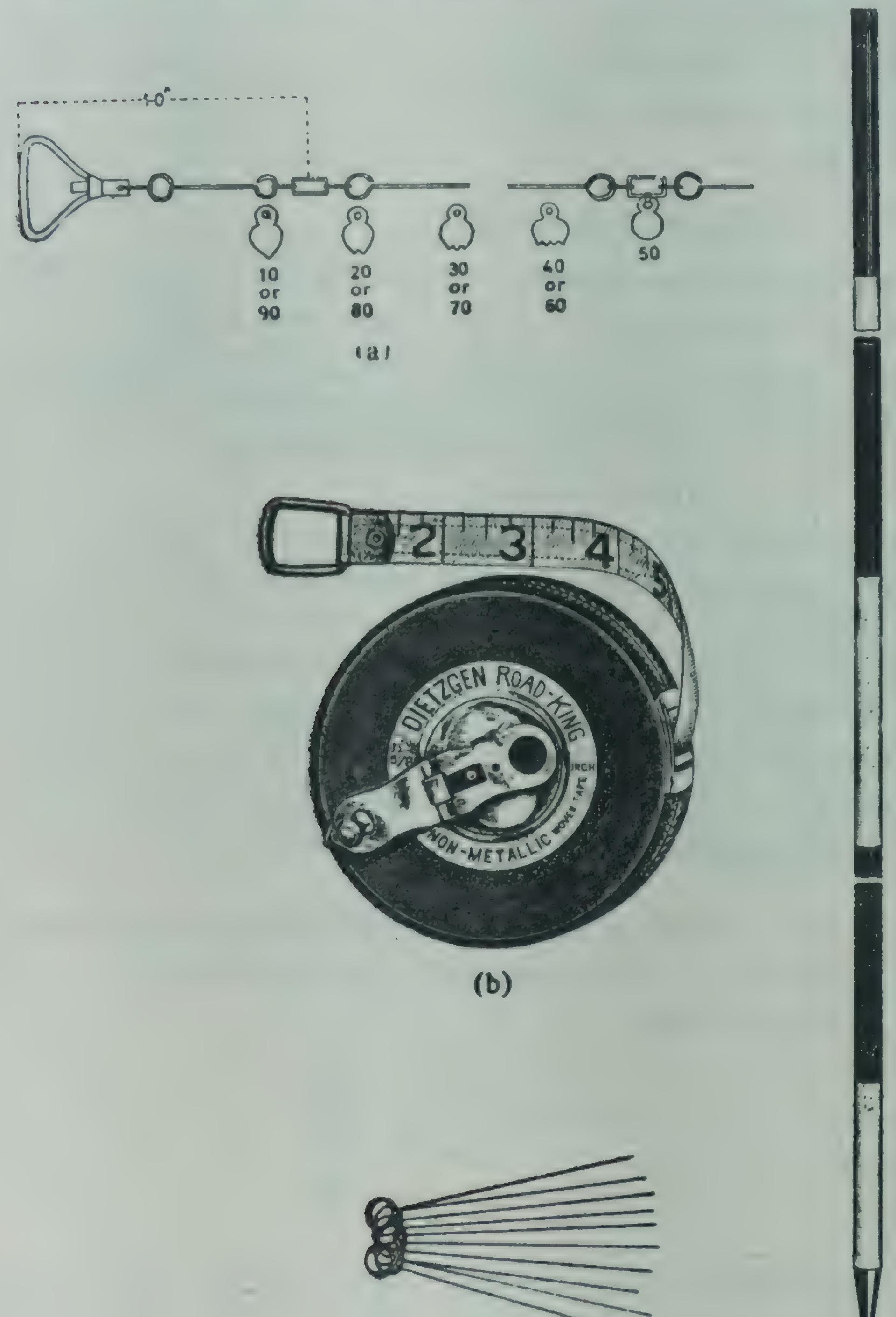
Chain: Chain is made of steel wire. It consists of 100 links. An Engineers chain is 100 ft. long and a gunter's chain is 66 ft. long. Gunter's chain used to be common in India because it is convenient in measuring acrage and mile-distances. 80 chains equal 1 mile and 10 sq. chains make an acre. As against this, the engineer's chains has the advantage of easy counting in decimals. In countries like India where metric system of measurements is now in vogue chains of 10, 20 or 25 meters are used. These chains are also divided into 100 links.

A chain has two brass handles at its two ends. To facilitate the counting of links, a brass tag is attached at every tenth link. The tags have 1, 2, 3 or 4 teeth to indicate the number of links.

One tooth	10 or 90 links
Two teeth	20 or 80 links
Three teeth	30 or 70 links
Four teeth	40 or 60 links
No tooth	50 links.

Tapes: Tapes have greater variety in their length and make than chains. The length of a tape may vary from 2 feet to 1000 feet. There is a great variety of the materials of which they are made. Those in common use are cloth tapes, metallic tapes and steel tapes. Cloth tapes are made entirely of cloth and, therefore, expand or contract with changes in weather conditions. These are not suitable for precision measurement. Metallic tapes are ctoth tapes with metallic threads twisted with tinsel. They are not as seriously affected by changes in weather as the cloth tapes. Steel tape is the best among the three.

It is made of special steel which does not expand or contract easily. It has the additional advantage of being sturdy and, therefore, suitable for rough use.



(c) (d)

Figure 76 : Some instruments used in chain surveying : (a) chain (b) tape (c) arrows (d) ranging rod.

Off-set Staff : It is a round or square wooden staff of 10 feet length with a pointed iron shoe on one side. It has 10 divisions, each division being marked by alternate colours (red, black, or white).

Ranging Rods: Ranging rods are used to indicate the position of an object or point in the field. These are made of bamboo or wood and are coloured to aid visibility.

Arrows or Pins: These are iron nails 15″ to 18″ long with a loop at the top. Arrows are used to mark the length of a chain on the ground. In the process of measuring horizontal distances, the surveyor fixes an arrow each time he measures one chain.

Wooden Pegs: Arrows are removed after the full length of a line has been measured. But in certain cases the surveyor may like to refer back to some of the points on the line already surveyed. To keep such points distinct and visible wooden pegs are fixed.

Magnetic Compass: It is used to determine the magnetic north.

Optical Square: While measuring the distances of objects or points close to the chain line an optical square helps in setting out right angles. Two mirrors fitted vertically on a brass plate and inclined to each other by 45° form the basic parts of the square.

When and how to do Chain Surveying?

Chain surveying has the advantage of being relatively simple, inexpensive and moderately accurate. This can be used for following purposes:

1. to show property lines,
2. to survey a small area,
3. to survey a flat area,
4. when time factor in surveying is not crucial. Chain surveying is a slow process; it is, therefore, not suited for quick surveys, unless the area to be surveyed is very small.

Chain surveying is of two types: (1) open traverse, and (2) close traverse. In open traverse, the surveyor does not come back to his starting point. This often happens in the case of route surveys. In the case of the closed traverse, the surveyor comes back to the starting point.

Procedure

Before starting the survey,

1. Make a sketch of the area to be surveyed and locate all the prominent objects in this sketch.
2. Divide the area included in the sketch into convenient number of triangles and mark their vertices on the ground by wooden pegs.
3. Determine the magnetic north with the help of a magnetic compass.

While dividing the area into triangles, make sure that the vertices of the triangles or station points are free from obstacles and are easily accessible. And that:

1. the number of stations are as small as possible,
2. the triangles are equilateral or near equilateral,
3. the size of traingles are as large as possible, and
4. the sides of triangles, as far as possible, run along the bounding lines of the area and close to the objects so that the off-sets are not too far away.

After these preliminary steps, the chaining can be started from any of the several points selected as stations. A ranging rod is fixed at the opposite end of the line. The chain is stretched along the line. Before the chain is pulled forward, off-sets to all the objects falling within the range of the first chain length are taken with the help of a tape and an optical square. All offsets must be vertical to the chain line. The distances of the offsets from the chain line and from the starting point to the point where the off-set line meets the chain line are measured and recorded in a field book, an example of which is given later in this section. The data so recorded are then plotted on a map of suitable scale. The preparation of the map completes the chain survey.

In a chain survey at least five persons are needed. Two persons handle the chain, two others measure the off-sets and one person prepares the field book. The front man holds one of the handles of the chain and walks from the starting point to the end point. He carries 10 arrows with him. When he walks approximately a chain length, the rear man instructs him to stop by shouting 'chain.' The rear man then instructs the front man to be on the straight line by aligning him with the object or the ranging rod fixed at the end of the line. Kinks, if any, in the chain are removed and the chain is straightened. The frontman then fixes an arrow at the end of the chain. The men deputed to take offsets finish their work and the field man records the data in the field book. After all this is done, the front man pulls the chain forward. The whole process is repeated until the front man reaches the end of the line. The rear man goes on collecting the arrows fixed at the end of each chain length. The number of arrows in the hands of the rear man gives the length of the line measured. The party then moves to the next point and repeats the process.

Let us take an example of an area to be surveyed as given in fig. 77. We start from point A and move toward point B. The chain is stretched on line AB with one end of the chain being at A. The chain is straightened and

aligned. An offset aa is measured. The distances between Aa and aa are recorded in the field book as shown below. Similarly distance Ab, Ac, bb and dd are also recorded. It may be restated here that all off-set distances are measured along straight lines drawn as perpendiculars from the objects to the chain line.

For fig. 77, there will be five field book records, one each for lines AB, BC, CD, DA, and EA, in the same way as given for AB. The data given in the field book are reduced to scale and the map of the area is drawn.

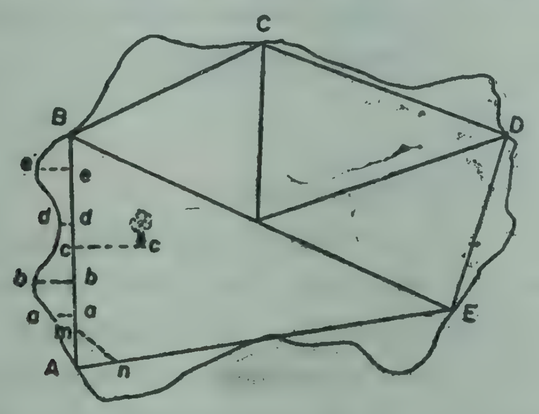


Figure 77: Procedure for chain survey.

The field book in which all the measurements are recorded has three columns. The central column is enclosed and is intended to record the measurements along the chain line. Starting with the bottom of the column, the starting point is noted and then distances of all points at which offsets are taken are recorded. The side columns are utilized to record the length of offsets. Offsets on the right side of the chain line are recorded in the right hand column and those on the left side in the left hand column.

	B	
	180′	
Boundary 30′	156′	
Boundary 10′	114′	
	96′	55′ tree
Boundary 36′	68′	
Boundary 18′	40′	
	A	

From A to B.

Some Problems in Chain surveying:

In chain surveying we measure only the horizontal distances. This is easy to do if the ground is not slopy or if there are no obstacles in the way of the surveyor. If the ground is slopy we can use one of the following formula to convert the actual distance into horizontal distance.

These are:

(1) $X = L \cos A$,

Where X = horizontal distance

L = actual length along the slope

A = slope in degrees

(2) $X = L - \dfrac{h^2}{2L}$

Where h = the height.

L = actual length along the slope

Those who cannot work with the above formula can use what is commonly called measurement-in-steps. The method is illustrated in fig. 78. A ranging rod is fixed at B. With the help of a tape, the horizontal distance Ab is measured and recorded. Same is done between B and C, and C and D.

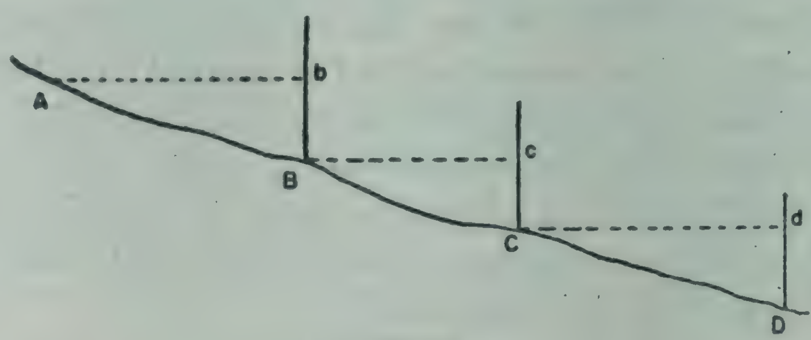


Figure 78: **Measurement-in-steps along a slopy ground.**

If there are obstacles in the way of measurements the following procedure is suggested. Let us suppose that we have to measure the distance between two objects located on two opposite sides of a river, or on two sides of a pond. If latter is the case, we can measure three perpendicular distances as shown in figure 79a. In this fig. PQ = XY. In case the objects lie on two sides of a river, the method illustrated in fig. 79b can be used. In this case point B is fixed on the other side of the river. Both A and B fall on the same chain line AO is drawn perpendicular to AB from A and produced to Q, making AO = OQ. QP is drawn parallel to AB. It is also perpendicular to AQ at Q. Point P lies in a straight line POB. ∠AOB and QOP being opposite, are equal and hence AB = PQ.

Another problem that one faces in chain surveying is the exact measurement of the angles that different sides of a triangle make. This may become a real problem if one has to make an open traverse survey. In this case there are no triangles. Even in the case of closed traverse one may come across some unavoidable obstacles in the way of measuring one of the lines of a triangle. In chain survey we must know the length of all the sides of the triangles to prepare a map, for we do not measure the angles.

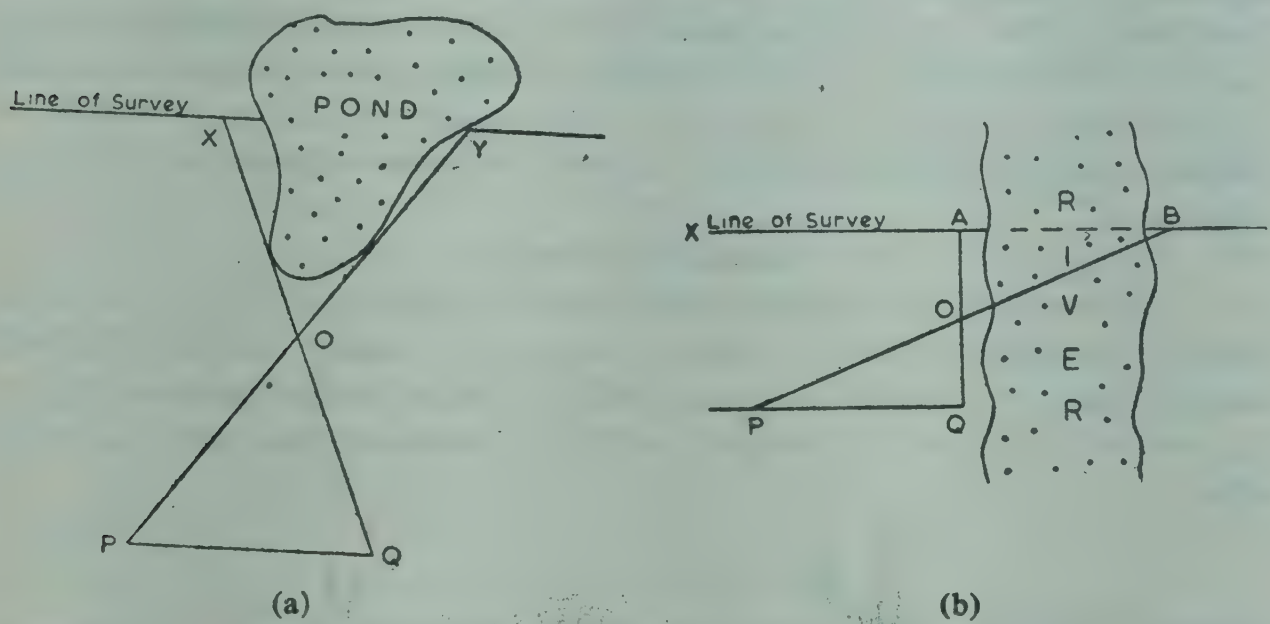


Figure 79 : (a) Horizontal measurements across a pond. (b) Horizontal measurements across a river.

To solve this problem we can measure what we call tie lines. A tie line is one that connects two sides of a triangle to make a small triangle in one of the corners. This is shown in figure 77. In this figure there is an obstacle between points A and E which forbids the measurement of the line. We, therefore, establish points *1* and *2* on AB and AE respectively at convenient distances and measure the tie line *mn*. With the help of this tie line we can draw lines AB and AE without knowing either angle BAE or line AE.

Errors in Chain Surveying

Most of the errors in chain surveying result from the carelessness of the surveyors in handling the equipment or from the defects in instruments. If the instruments are defective, errors will be repetitive and will grow cumulatively as work proceeds. Some of the common causes of errors are mentioned below.

1. Length of the chain is not correct,
2. Chain is not alligned and stretched properly,
3. Chain or the tape is not horizontal,
4. Ranging rods or arrows are misplaced,
5. Fieldman did not record the date correctly.

PRISMATIC COMPASS SURVEYING

We have seen how chain surveying is based on the measurement of horizontal distances. Even where measurement of angles becomes necessary we resort to the measurement of tie lines. Suppose we have to construct a quadrilateral A B C D. If we know the angles, A,B,C, and D and any two of the sides, we can make this figure. Another way we can draw this figure is by knowing the angles each of the lines AB, BC, CD, DA, DB and AC make with a north-south line. In the latter case, we will need to know the length of only one line. The prismatic compass surveying is based on the principle of measuring the angles that different lines make with respect to a N-S line. Only one line is measured to maintain the scale relationships between the ground and map details.

PRISMATIC COMPASS

To determine the angle each line makes with a north–south line, we make use of a prismatic compass. Figure 80 shows a prismatic compass and the bearings marked in it. It is like any ordinary magnetic compass except that it has a prism, an eye vane at one end, and an object vane with a hair-line at the other.

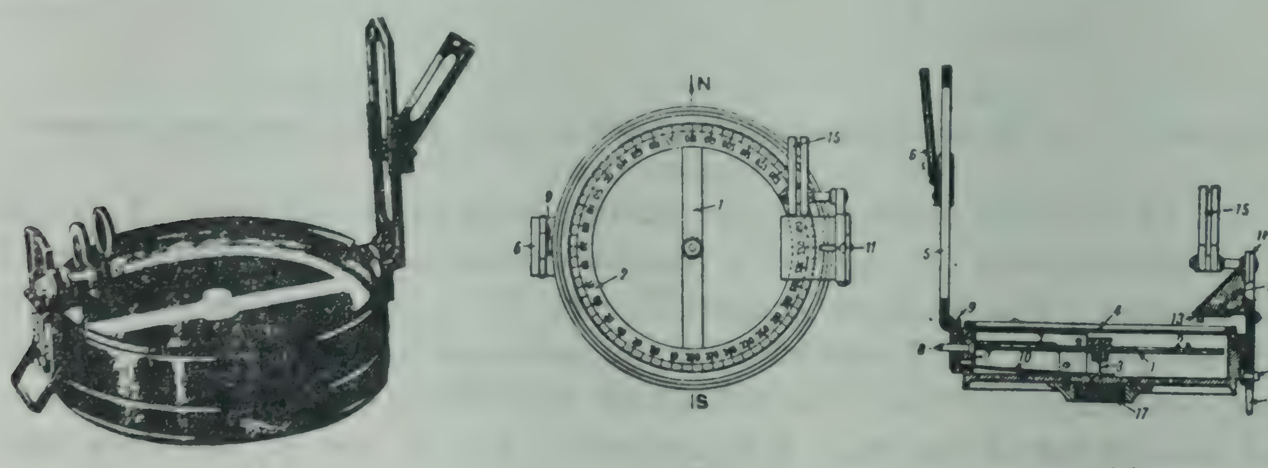


Figure 80 : Prismatic compass and its parts.

1. Compass needle. 2. Compass ring. 3. Pivot. 4. Glass cover. 5. Object vane. 6. Adjustable mirror. 7. Spring brake. 8. Brake pin. 9. Lifting pin. 10. Lifting lever. 11. Eye vane. 12. Prism. 13. Prism dust cap. 14. Focussing stud for prism. 15. Hinged sunglasses. 16. Hinged strap. 17. Screw for jacob staff.

The eye vane, the centre of the compass, and the thin wire fixed vertically in the object vane make a straight line. Both the prism and the sight vane are hinged so that they can be folded horizontally. A magnetized needle is pivoted at the centre. One end of this magnetized needle is coloured or made distinct. The coloured end points to the magnetic north. Usually there are

two rows of graduations on the disc. The inner row has its north point marked 0° or 360° and the south point 180°. In the outer row the 0° or 360° are marked at the south point and 180° at the north–point and the figures are given in reversed image. In many compasses the graduations run only from 0° to 90°. The reversed figures show up through the prism in a magnified and up-side down form (correct form) while sighting an object. The magnetized needle is fixed to the disc on the 0°–180° line. As the needle moves to point the magnetic north, the disc also moves along with it. So that when we look through the prism, we read the angles that the object sighted makes with the magnetic north.

To facilitate the sighting of luminous objects, the prism is fitted with a pair of coloured glasses which can be fixed on the line of sight. In addition to these a sliding plane mirror is also fitted to the frame of the sightvane. This mirror can be adjusted to any angle and thus the bearings of the objects which lie too far below or high up the plane of the compass can be conveniently read.

The angles read with the help of a prismatic compass are called bearings. A bearing is an angular measurement with respect to a reference direction. If the reference direction is magnetic north, the bearings are called magnetic bearings; if it is true north, then true bearings. In the case of the prismatic compass survey, we deal with magnetic bearings only.

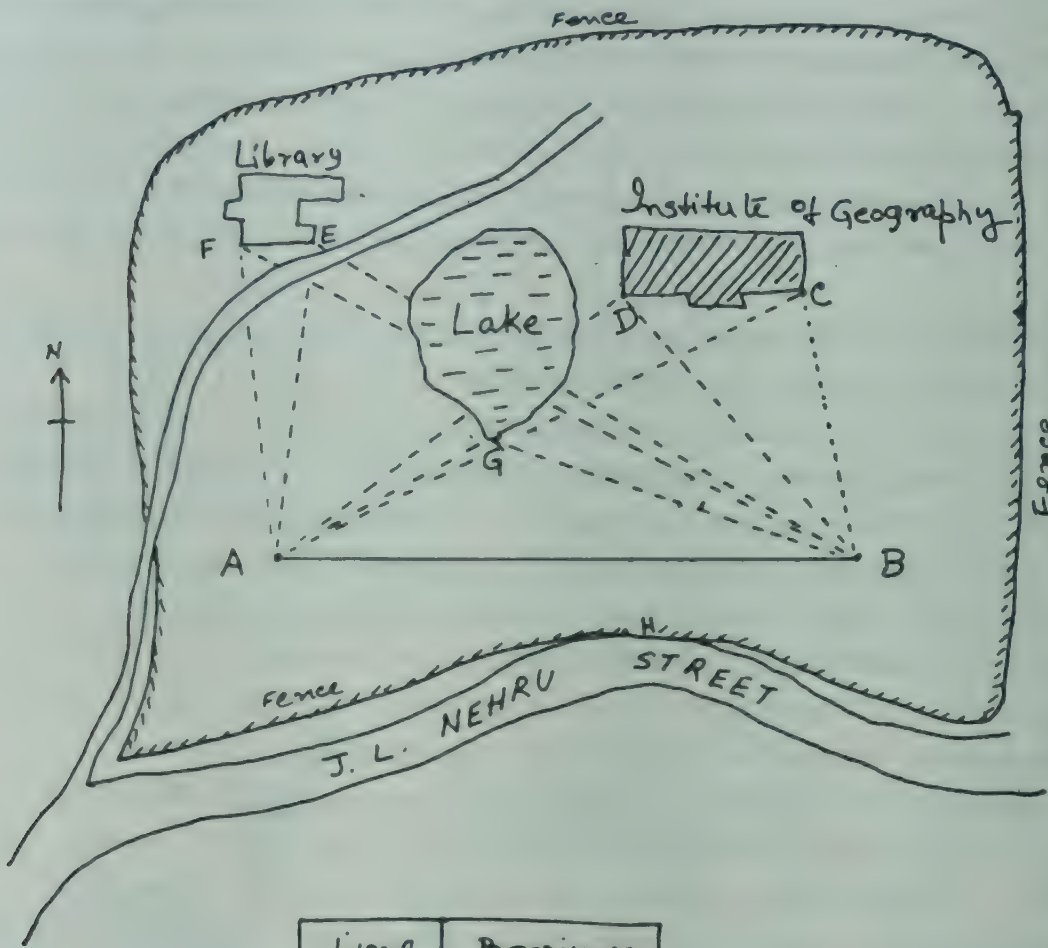
There are two systems of expressing bearings: (1) Whole circle system (W.C.S.) and (2) Quadrantal System. The whole circle system runs from 0° to 360°. This system is the one which is used in most of the prismatic compasses and also one which has been explained earlier. In the quadrantal system the bearings run from 0° to 90° and are preceded by N or S and followed by E or W to indicate the quadrant to which they belong. The first quarter of the circle is NE. If 50° bearing is to be shown, it will be shown as N 50 E. The second is SE, the third SW and the last NW.

PROCEDURE

The first step in prismatic compass survey, as in all other surveys of lower orders, is to prepare a sketch showing the objects for which bearings have to be recorded. Then a base line is selected. The base line should be such that its two ends are inter-visible and easily accessible. The objects to be located should also be clearly visible from both ends. In fig. 81, AB is the base line and C, D, E, F and G are the points for which bearings have to be noted.

To start with, the compass is set at A. The compass must be in the horizontal position to enable the magnetic needle to swing freely. Lift the prism and allow the needle to come to rest. Fix a ranging rod at B. Look through the prism and make the hairline of the object vane intersect the

ranging rod. Read the bearing of line AB and record it on the field book as shown below. Similarly, read the bearings of all other objects and record them in the field book.



Line	Bearings
AB	90°
AF	353°
AE	8°
AD	53°
AC	64°
BC	351°
BD	330°
BE	301°
BF	297°
BA	270°

Figure 81 : Procedure for compass surveying

The next step is to measure the length of AB. It should also be recorded in the field book. Now place the compass at B. After levelling, read the bearing of A from B. This bearing is called backbearing. Whereas the bearing from A to B (90°) is called forward bearing. The difference between the two bearings should always be 180°. Read the bearings of other objects also and note them in the field book.

In many cases the objects selected for representation on a map are so close to the traverse lines that the recording of their bearings is not necessary. We can use such objects as off-sets and note down the perpendicular distances from the line of sight to the object as in chain surveying. The distances at which the offset lines meet the line of sight can be recorded in the same way as in the case of chain surveying.

Like chain surveying, compass surveying is also of two types: (1) Open traverse; and (2) Closed traverse.

Open traverse is one in which the surveyor does not come back to the starting point as in the case of a route survey (fig. 82). The surveyor starts

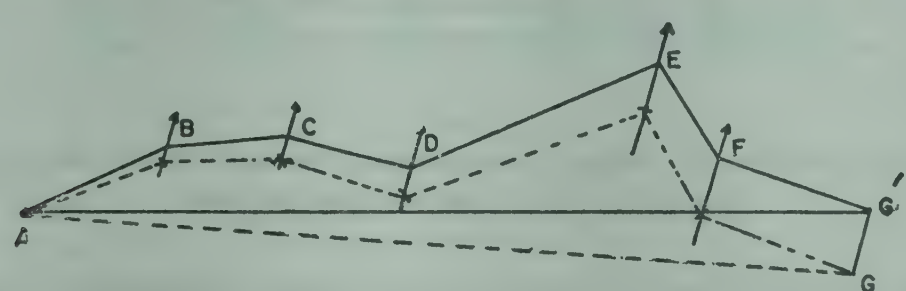
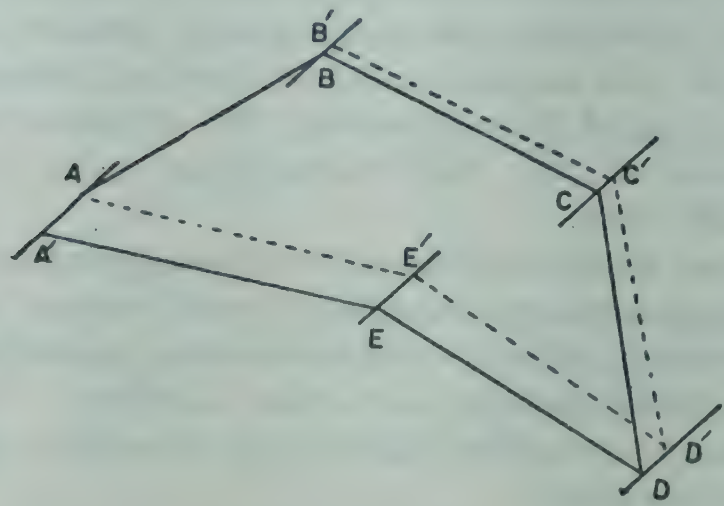


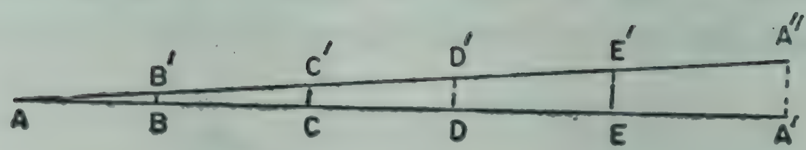
Figure 82 : Open traverse in compass surveying. Dotted line shows the corrected traverse.

from A, reads the forward bearing of B and moves on to B after measuring line AB. He then takes the back bearing of A and the forward bearing of C and repeats the process of measuring the line and moving to C, D, etc. While measuring the lines, he also takes the offsets wherever necessary. In a closed traverse the surveyor comes back to the starting point. If he starts from A, he comes back to A after passing through other points as shown in fig. 83.

After the field work is over, the surveyor comes to the laboratory to plot the data recorded in the field book. The first thing that he does is to mark a magnetic north-south line at the starting point. From that point and with reference to N-S line he marks the respective bearings recorded in the field book. For example, in figure 83 our starting point is A. If the forward bearing of AB is 10°, then we will mark this and draw line AB to its proper length. We then move to point B, and repeat the processes for other lines until we come back to A.



(a)



(b)

Figure 83 : Closed traverse in compass surveying and the method of correcting the error. Dotted lines show the corrected traverse.

If the bearings are taken and recorded correctly and there are no mistakes in plotting, BA and EA would meet at a common point A. But, more often than not, they would not meet and may deviate as shown in fig. 82 and 83.

SOURCES OF ERROR AND METHODS OF CORRECTION

The errors in prismatic compass surveying may be due to one or several of the following reasons :

1. Presence of iron in the area surveyed,
2. defects in the compass,
3. errors in observation,
4. wrong recordings in the field book, and
5. wrong plotting.

Magnet attracts the iron, so if iron pipes, etc are present in the area surveyed, the bearings will not be correct. Errors may also result from the use of defective instruments. Very many errors result from wrong observations. At times the bearings are wrongly recorded in the field book, at others the plotting is not done correctly.

There are three methods of correcting the errors noted above. These are :

1. Proportional distribution,
2. Re-checking, and
3. Plotting by included angles.

Proportional distribution :

If we happen to observe a closing error as shown in figure 83 (a), we can distribute the total error in such a way that points A and A′ will meet at a common point. The principle of proportional distribution implies that the total error AA′ should be distributed proportionately at all the points, B,C,D,E and A, to make the whole plan graphically balanced. The method of distribution is as follows. Draw a straight line AA′ equal to the parameter (total length of all lines). At A′ draw a perpendicular A′ A″ = to A A′ of the traverse. Join A and A″. Mark distances equal to AB, BC etc on A A′ and errect perpendiculars to meet A A″ at B′ C′ D′ and E′.

Now in the traverse draw lines at all the points parrallel to AA′ and from these mark distance BB′, CC′, etc. at their respective places. Connect these points. This new figure A B′ C′ D′ E′ will be the corrected figure. (fig. 83a)

Re-checking :

In those cases where the existence of iron in the area surveyed distorts some of the bearings, we can correct them without resorting to the graphical method given above.

Let us suppose that the following bearings were recorded in a survey.

Line	*Forward bearing*	*Back bearing*
AB	14°	192°
BC	58°	238°
CD	137°	313°
DE	218°	40°
EA	292°	116°

We know that the difference between the forward and back bearing of a given line should always be 180°. From the data given above, we find that this difference is found only in case of BC where 238°–58° = 180°. This means that the bearings taken at points B and C were not affected by the presence of iron. This being the case, the back bearing taken from B to A (192°) is also correct. The mistake lies in the forward bearing of A (14°), which apparently should be 12°. Similarly the forward bearing at C (137°) is also correct and the discrepancy lies in the back bearing of D (313°) which should be 317°. If the

discrepancy at D is equivalent to $+4°$, then forward bearing of D should be 222°, and not 218°, and hence the back bearing should be 42° The corrected bearings are given below:

Line	*Forward bearing*	*Back bearing*
AB	12°	192°
BC	58°	238°
CD	137°	317°
DE	222°	42°
EA	294°	114°

Plotting by included angles:

All the bearings will be wrong if the compass is defective. In such cases the difference between the forward and back bearings will never amount to 180°. The clue for the adjustment or correction of this type of error lies in the fact that a defective compass registers the same amount of discrepancy at all points. If we subtract the backbearing of a point from the forward bearing of the same point, we will get the included angle. In case the forward bearing is less than 180°, add 360° before deducting the back bearing. The included angles so obtained run clockwise and are measured with reference to the line joining the previous station to the station at which the bearings are observed.

Figure 84 explains the principle underlying this method. Let us suppose that X is the amount of discrepancy caused by the malfunctioning of the compass. The backbearing at point B is $= \angle a$, BN (lower) is the magnetic north line shown by the compass and BN (upper) is the correct magnetic north line. Forward bearing of B is b. If we deduct a from b, we get $\angle ABC$ which is an included angle. Here a is the backbearing and b the forward bearing. If we add X to both the bearings and deduct a from b, the value of the $\angle ABC$ will remain unchanged. Knowing $\angle ABC$ and all other included angles of a figure, we will have no difficulty in drawing the figure.

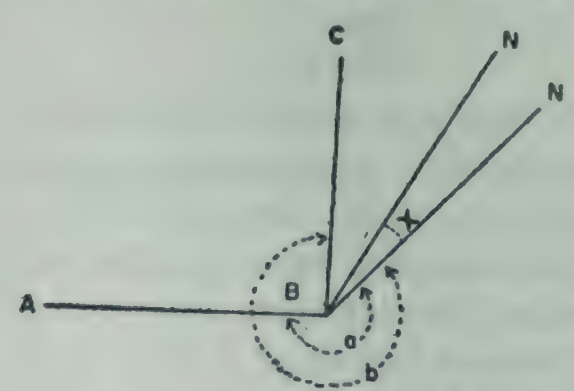


Figure 84: How included angles are not affected by wrong bearings resulting from magnetic influences.

A few examples of the method of calculating the included angles are given below. The data used are given on page 149.

Included angle A = (14° + 360°) − 116° = 258°

B = (58° + 360°) − 192° = 226°

C = (137° + 360°) − 238° = 259°

D = (218° + 360°) − 313° = 265°

C = (292° − 40°) = 252°

1260°

To Check whether the included angles are correct or not, one of the following two methods can be used:

1. The total of the included angles should be 2n + 4 right angles; Where n is the number of angles. 4 will be added if the angles are exterior, and subtracted if they are interior. In our example, all the angles are exterior ones. Hence the total of the included angles should be

   $2 \times 5 + 4$ right angles = 14 right angles = 1260°.

2. The other formula is a variant of the first. According to this, the sum of the included angles should be $2n \times 90 + 360$, where n stands for number of angles. According to this formula the total in our example should be

   $2 \times 5 \times 90 + 360 = 1260°$.

ADVANTAGES AND DISADVANTAGES

Advantages:

(1) Instruments used in the prismatic compass surveying are light and portable.

(2) Wrong bearings at one point do not affect bearings at other points. As such the error is not cumulative.

(3) It is most suited to areas which are very congested.

(4) It is quicker than chain surveying.

Disadvantages:

(1) Its results are vitiated by the presence of metals like iron near the place of surveying; and

(2) A magnetic compass is not a precision instrument. Like ordinary watches, different compasses may record different bearing for the same object.

PLANE TABLE SURVEYING

In the chain and prismatic compass surveying, the sides and bearings are measured on the ground, noted in a field book and finally plotted on a sheet of paper. Now we come to another type of plane surveying in which surveying and plotting go together in the field itself. The laboratory work does not involve plotting of the data ; it involves only fair drawing.

Plane table surveying is a graphical method of surveying. It is based on triangulation done graphically. It is one of the simpler methods of surveying. It is speedy also. The errors are easily detected in the field itself. The horizontal distance of only a base line is measured. The plotting is so done that the measurements of angles are not necessary. Plane table survey, unlike other types of surveys, can be completed single handed. There are no chances of discrepancies resulting from the presence of magnetic materials. Further, plane tabling can be stopped temporarily and taken up subsequently without having any adverse effects on survey results.

With the advantages listed above, plane table survey has certain disadvantages also. First, even small obstructions make plane tabling difficult It cannot be used in wooded areas, for example. Secondly, it is not suited to areas having frequent rains. The sheet of paper on which the results are plotted has to be used in the open. With sudden changes in weather the paper contracts or expands and the accuracy of the work is marred. It is not suitable for large scale surveys covering extensive areas.

EQUIPMENT

1. Plane Table : It is a drawing board fitted to a tripod. It can be rotated freely and fixed in any desired horizontal position. The table has a brass plate with a bossed head which fits into the hole of the plate of the tripod. It can be tightened with the help of a clamp to keep the table in a fixed position (figure 85).

2. Alidade : It is a ruler with parallel edges. There are two flaps at the two ends of the alidade. One flap has a slit and the other has a vertically fixed wire. The method of observing the objects is the same as in prismatic compass surveying. A telescopic alidade (fig. 86) is used to observe distant objects.

3. Chain and Tape : A chain or a tape is used to measure the base line.

4. Trough compass : A trough compass is a rectangular compass used to determine the magnetic north.

5. Spirit Level : It is used to set the table in a horizontal position. There is an air bubble in the level. If the table is fixed horizontally, the bubble rests in the centre. Some of the alidades are fitted with a spirit level.

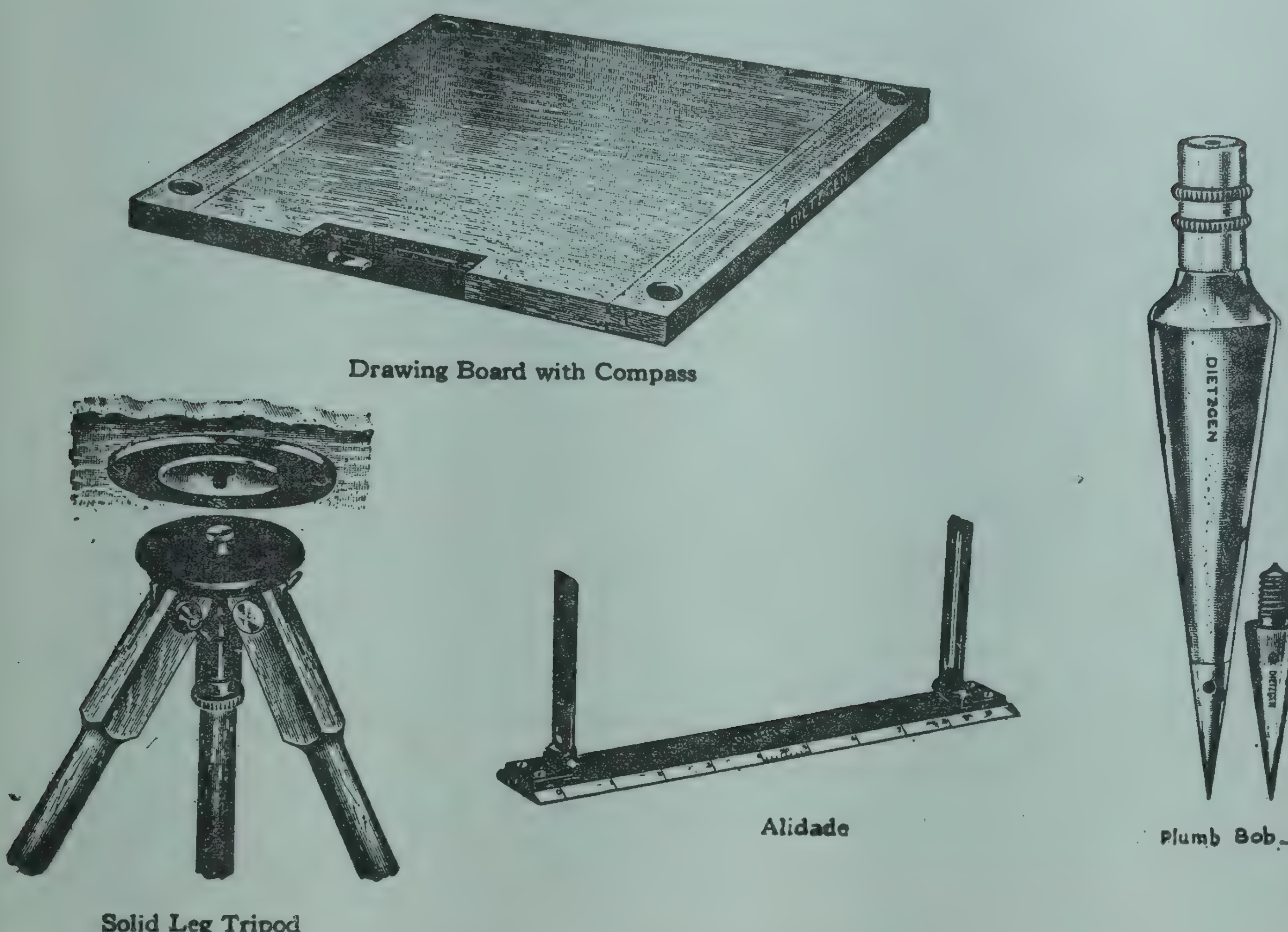


Figure 85: Plane table equipments

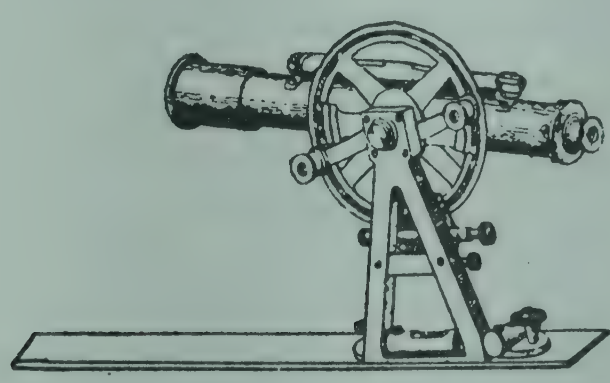


Figure 86: Telescopic Alidade.

6. *Ranging rods and wooden pegs:* These are needed for marking the stations or objects to be included in the survey.

7. *Plumb bob:* A fork or U-shaped frame with a plumb bob is used to centre the table exactly at the station.

8. *Field Glasses:* These are used to get a clearer view of distant objects.
9. *Thumb Pins:* Thumb pins are used for fixing the paper to the table.
10. *Drawing Equipment.*

PROCEDURE

Preliminaries: Before starting the actual survey, the surveyor should see that the equipments he is going to use are in perfect working order. The sheet of paper to be mounted on the table should be larger than the table so that it can be thumb pinned underneath the board of the table. It should not be pinned on the board because the pins will hinder the free movement of the alidade. They will also make the surface of the table rough.

Measuring the base line: The first step in plane table surveying is to select and measure a base line. A base line should be so selected that it almost occupies a central position in the area to be surveyed, that it is on a level ground, and that its ends afford sight of a few of the prominent objects. The line should be measured on the ground, then reduced to scale and drawn on the paper mounted on the board. The position of the base line on the paper should approximate its corresponding position on the ground (with respect to the features to be plotted on the map).

Centering and levelling: After the base line is drawn, the table should be placed at one of its two ends, in such a way that the starting point on the paper is exactly over its corresponding point on the ground. This can be done with the help of the plumb bob. To use the plumb bob the fork should be placed across the table in such a way that the upper blade of the fork is fixed at the selected point on the paper and the plumb bob attached to the lower fork points directly to the corresponding point on the ground. This is called centering the table.

While centering, the levelling of the table should also proceed with the help of a spirit level. Place the level on the board between any two legs of the tripod. When the bubble comes to stay in the centre, remove the level and place it in between the third and any of the first two legs. The table should now be adjusted by moving the third leg only in order to bring the air bubble of the level in the centre taking care to see that the centering is not disturbed. While doing so, one should keep in mind that the bubble will move in a direction opposite to the one in which the legs of the tripod are moved. A final checking can be done by placing the level at each corner of the table.

Orienting the table: After levelling the table, the fiducial edge of the alidade is aligned with the base line drawn on the paper. The board should be unclamped and turned to allow the surveyor to see the ranging rod fixed at the

other end of the base line on the ground through the alidade placed along the base line drawn on the paper. The hairline of the alidade and the ranging rod should be in the same line when seen through the eye vane. When this is done, the table is oriented. By 'Orienting the table' we mean the alignment of the base line drawn on the paper with that marked on the ground. It is done with a view to determine the map direction.

Laying the table in azimuth : After orienting the table, a trough compass is placed in one of the corners of the board. A line showing the magnetic north is drawn with the help of this compass. With this marking the table is said to be lying in azimuth.

LOCATING POINTS BY INTERSECTION

With the marking of direction, the surveyor is ready to draw rays to all the objects he wants to locate on the map. Before starting the drawing work he should re-check the levelling of the table. Without moving the table, the alidade is so placed that the selected point and the object to be sighted are on the same line when seen through the eye vane. A line should be drawn to indicate the direction of the object. This process should be repeated with respect to each of the objects. Ultimately, we will find an array of rays radiating from one end of the base line as shown in figure 87. As the rays to different objects are drawn, the names of the objects are written along them to distinguish them from each other.

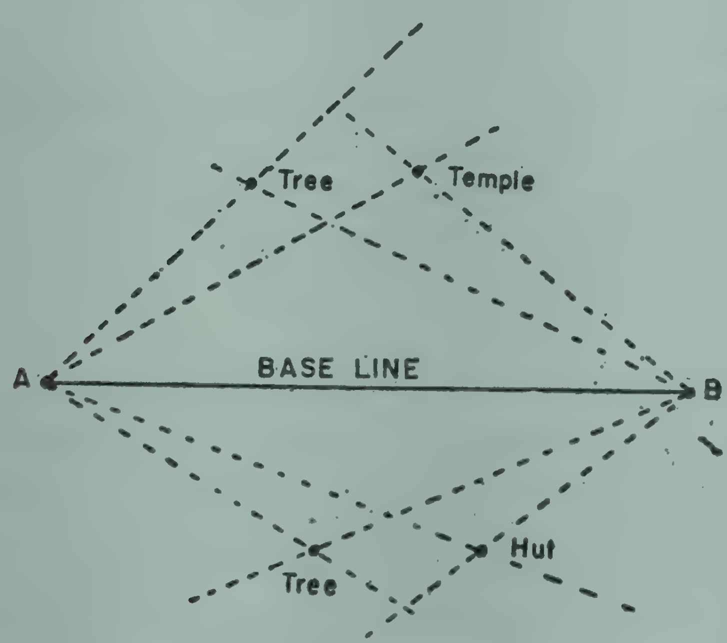


Figure 87 : Locating points by Intersection

After completing the work at one end, the table is placed at the other end. In figure 87 the other end is B. We repeat the whole process of centering, levelling, and orienting the table to the drawing of rays. The location of

the objects sighted is at the intersection of the rays drawn from the two points. After the locations are marked, the rays can be rubbed off.

The process of plane surveying as discussed above is a simple one. Here rays are drawn only from two points A and B. But there are cases where an object is visible from A but not from B. If such objects are also to be located, the surveyor will have to go to a third or even a fourth point to repeat the process of drawing the rays. The process of locating objects by means of drawings rays is called intersection.

LOCATING POINTS BY RESECTION

Resection is done in cases in which the plane tabler is asked to show a few more objects in between the objects already shown on a map. To do so, he goes to the field with part of the data already given on a map. In this case, he cannot just establish himself anywhere he likes and start drawing rays. First of all, he has to locate his own position with respect to the objects already shown on the map. This he does by drawing rays to the known points from his unknown position. This amounts to following a procedure just opposite to the one followed in *intersection.* That is why the process is known as *resection.*

Resection problems are of two types: (1) two point problem, and (2) three-point problem.

Two point problem:

Let us suppose that there are two well defined points A and B on the ground which are visible from station P, over which the plane table is set. The positions of these two points have been already plotted on the plan or map as a and b. We are required to locate other points on the plan. To do this, we have, first of all, to determine the ground position (p) of the surveyor on the plan.

This can be done by using the following procedure:

1. Choose an auxiliary point C on the ground in such a way that ∠PAC and ∠PBC are not too acute (fig. 88). In other words these angles should not be less than 30°.
2. Set the plane table at C; level and orient it with the help of a spirit level and magnetic compass. The orientation can also be done by maintaining ab parallel to AB.
3. Placing the alidade at a, sight A and draw a ray. Similarly sight B from b and draw a ray. These two rays intersect at c′. c′ is the approximate location of C.

4. Sight P from c′ and draw a ray c′ p′.
5. Now shift the table to P. Level it. Orient the table by backsighting c′. Clamp the table. Assume a point p′ on p′ c′ as the position of P on the plan.
6. Sight A from p′ and draw a ray p′ A. Sight B from p′ and draw a ray p′ B. The rays will pass through a and b, provided that the initial orientation of the table at C and P was correct. If it was not correct, p′ A may intersect c′ a at a′ and p′B may intersect c′ b at b′ as illustrated in fig. 88.

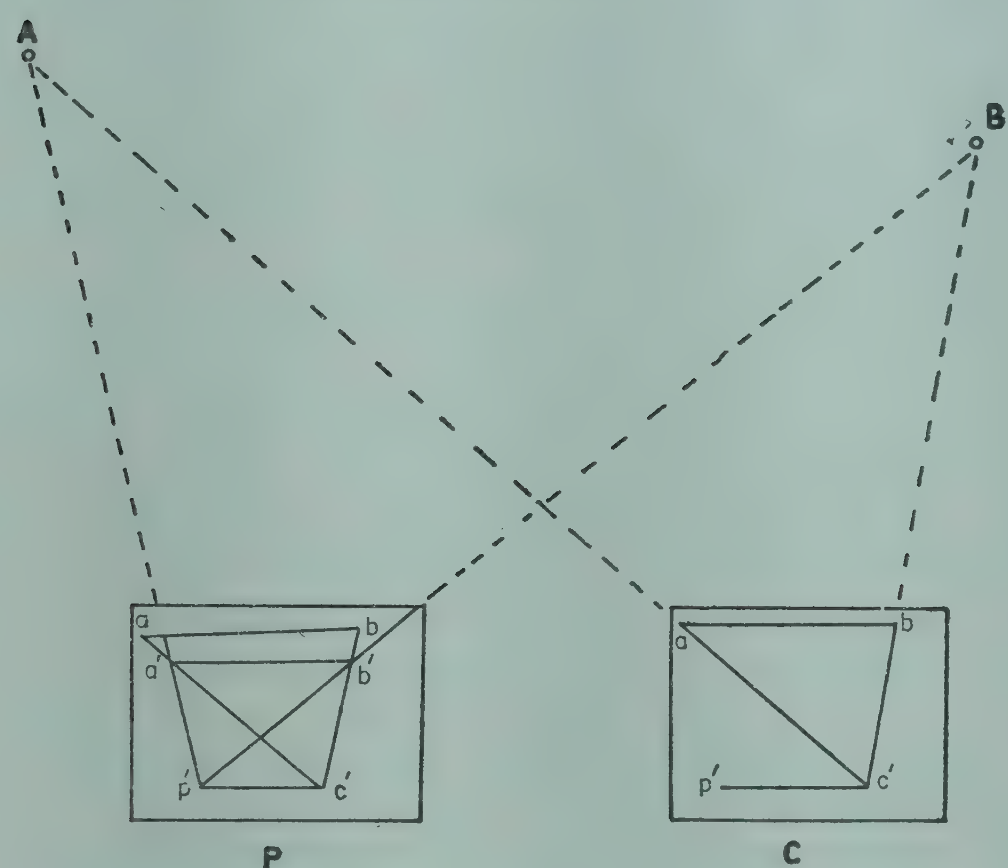


Figure 88: Locating points by Resection; A two point problem.

To eliminate the error, the following procedure is suggested :

(a) Fix a ranging rod R at a distance, so that a′b′ and R are in the same line.

(b) Place the alidade along a′ b′ and bisect R and extend the ray up to r. Place the alidade along ab and turn the table until R is bisected. Now the orientation is maintained. Clamp the table. Now ab is parallel to AB.

(c) To determine the correct position of C, sight A through a and draw a ray. Sight B through b and draw a ray. The intersection of

the two gives the true position (c on the map) of the station C. Similary to determine the correct position of p, sight A from a and B from b. The intersection of the two marks the correct position of p.

Three Point Problem:

There are three methods of solving a three point problem. These are (1) graphical, (2) mechanical, and (3) Lehmann's Method.

Graphical Method: Supposing that three ground points A, B and C are represented on a plan as a, b and c. A surveyor is asked to determine the location of a few more ground objects on the map. To do this, he has, first, to find out his own ground position on the plan. Once he is able to do this he can draw rays to the required points by intersection method.

The procedure used in the graphical method of solving the problem is as follows: (See fig. 89a)

1. Set the plane table at a ground station T. Level the table. Turn the board, so that a is towards A. Place the alidade along ab. Sight A. Clamp the table. Sight C through b and draw dbd′.
2. Unclamp the table and place the alidade along ab. Turn the table until the ground point B is bisected, a being towards B. Clamp the table. Draw ad toward c through a meeting dbd′ at d (fig. 89b).
3. Unclamp the table and place alidade along ac (fig. 89c). Turn the table to sight C. Clamp the table. The table is now oriented. It must be on dc, or dc produced. It must also be on Aa and Bb. To get the point, bisect A through a. The meeting point p between Aa produced and dc produced is the location of point T.
4. To be doubly sure, check the orientation of the table and bisect B through b. If the location of T is correctly determined, this ray will pass through p. Otherwise it will form a small triangle which can be eliminated by trial and error method.

Mechnical Method: To illustrate this method we assume to have a map which represents three points, A, B and C on the ground, as a, b and c respectively on the plan. Fasten the map on the plane table so that it is not allowed to change its position. Pin a tracing paper on the plan. Now level the table and select a point p on the tracing paper to represent your ground position. Draw rays from p to A, B and C. Release the tracing paper and move it on the plan without altering the position of the board to make the rays drawn on it pass through a, b and c on the plan. The point just below point p on the tracing paper will be ground position P on the plan. If owing to

careless manipulation or unequal stretching of the tracing paper, a small triangle of error is formed, it can be eliminated by trial and error method.

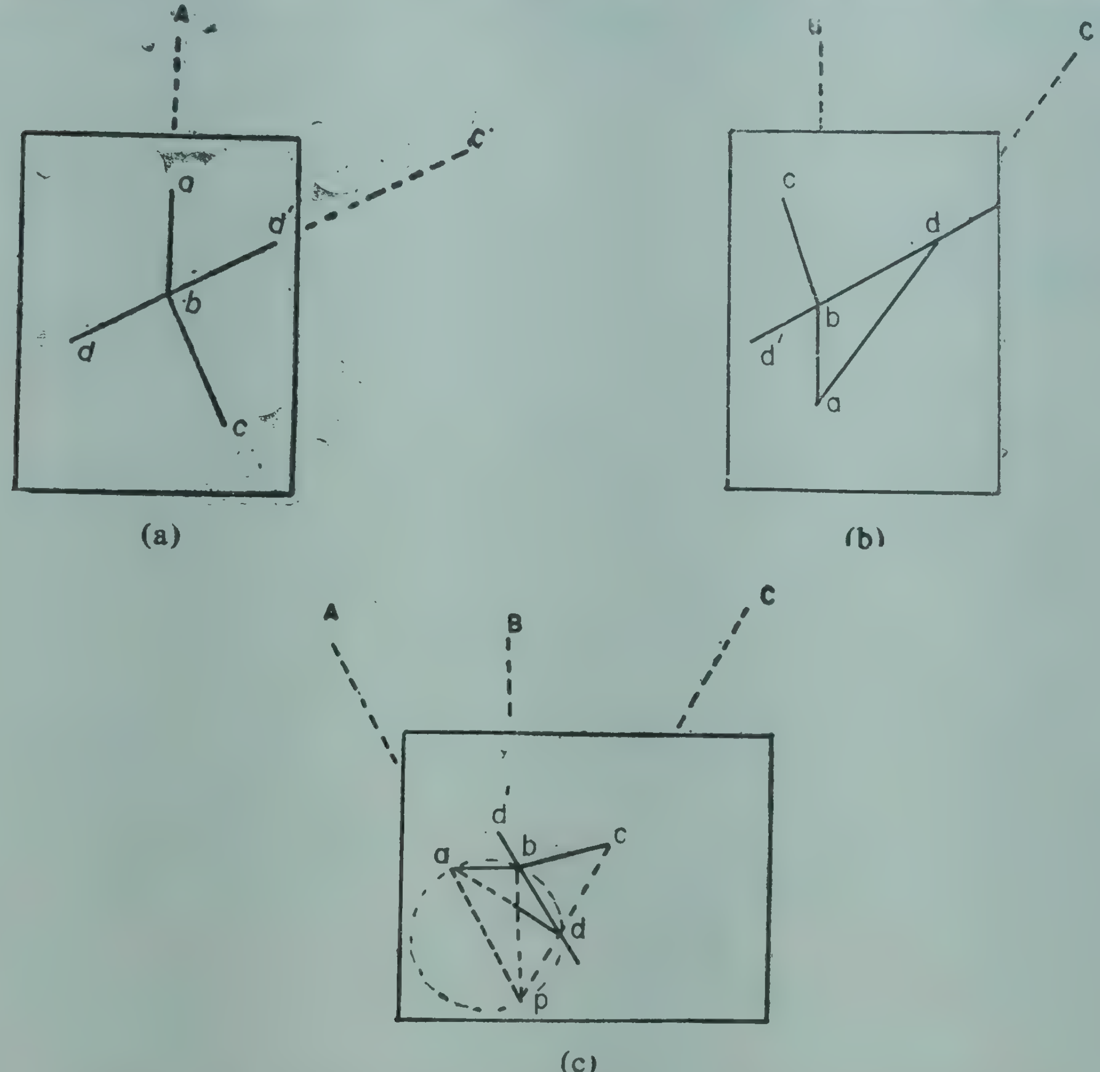


Figure: 89 Locating points by Resection : A three point problem.

Lehmann's Method: This method is also known as trial and error method. To use the previous example, we assume to have three known points A, B, and C on the ground. These points are represented by a, b and c on a plan. After levelling the table draw rays from A, B and C, passing through their respective positions a, b and c on the plan. If every thing is all right, the three rays will meet at a single point to give the location of the surveyor. In case the table was not properly oriented or levelled, a triangle as shown in fig. 90 will be formed. This tringle is called the triangle of error.

The position P of the surveyor will be either within the triangle of error, or on the right or left of the triangle of error.

The size of the triangle of error will depend upon the angular error in the orientation of the table. From this triangle the true position of p may be

estimated and by second trial a new triangle of error may be obtained which will be smaller than the former. By successive trials this triangle may be made so small that it becomes almost a point.

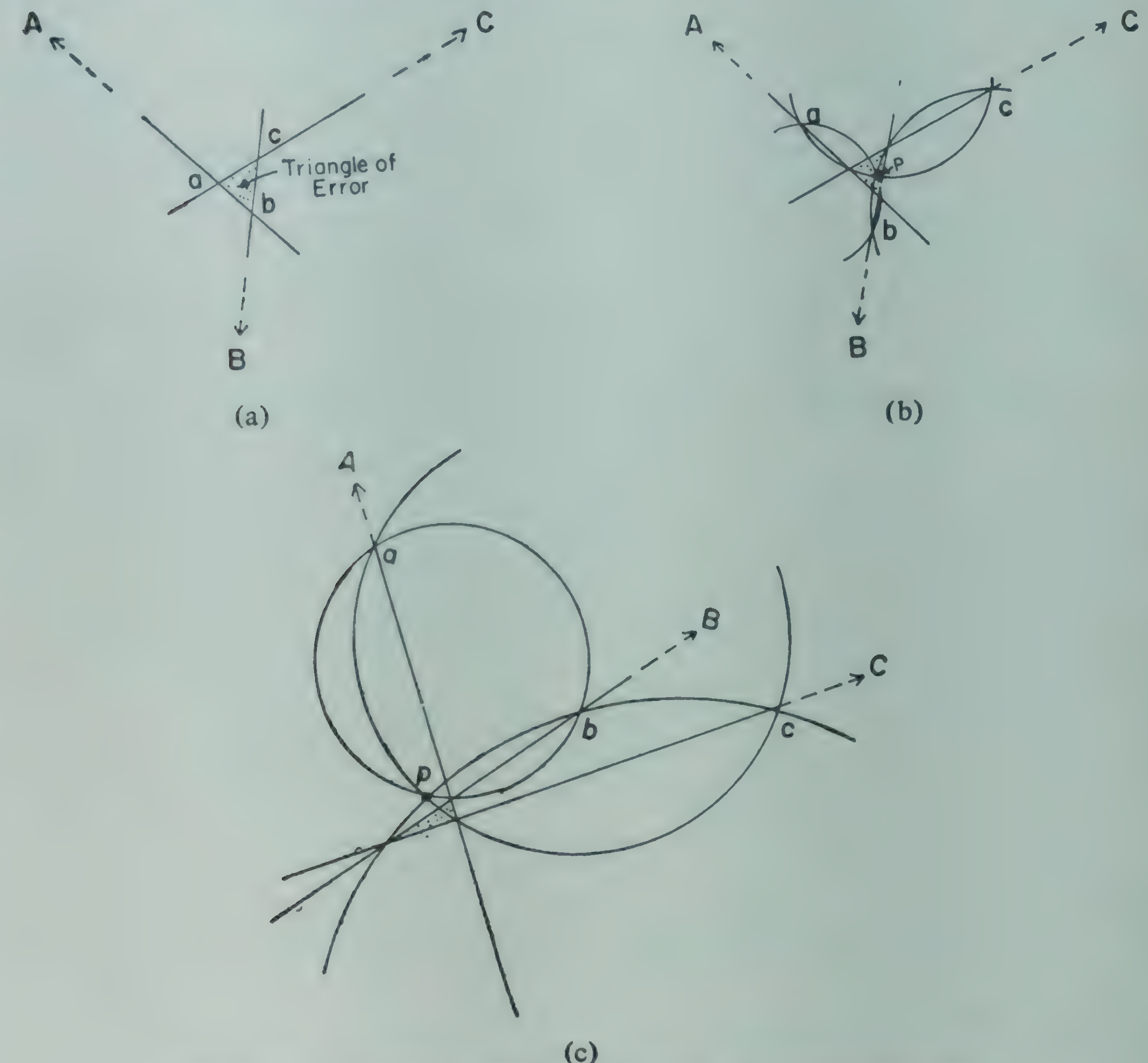


Figure 90: Lehmann's method of solving a three point problem.

In estimating the correct position of point P on the map, after the first triangle of error has been drawn the following geometic relations will be found useful. (1) If the table is inside the triangle ABC, the point p is inside the triangle of error, (2) If a circle is drawn through a, b and the intersection of the corresponding resection lines it will pass through the true position of p, for the angle made by any two resection lines from a and b is the angle APB. Similarly a circle drawn through a, c and the intersection of the corresponding resection lines will pass through p. A corresponding circle through b and c would also pass through the intersection of these two circles which is the true

position of p. Hence the intersection of these circles will give the positon of point p. (see figure 90a and b). This is called *Position circles method.* And (3) The distance of p from any resection line is proportional to the distance of the table from the point from which that line was drawn i.e., if the table is nearer B than the other points, the p will be nearer the resection line drawn through b than to others.

To check whether the position of point p is correct or not, draw rays from A, B and C passing through a, b and c. If they all intersect at point p the position is correctly determined. If a triangle of error is formed, use the method of position circles explained earlier to get the point.

USE OF A TELESCOPIC ALIDADE

A telescopic alidade (fig. 86) is used in plane table surveying when the work has to be completed in a short time. Only one ray is needed to locate an object if a telescopic alidade is used because we can read the horizontal as well as the vertical distances with the help of this instrument. We can see objects located at greater distances also with the help of this intrument.

Both the vertical and the horizontal diameters of the diaphragm of the telescope are ruled over it. On the vertical diameter, there are two or four lines called stadia lines. An assistant stands at the object with a vertically held staff having graduation of feet meter and hundredths of a foot meter (fig. 91). The observer looks at the staff through the telescope whose stadia

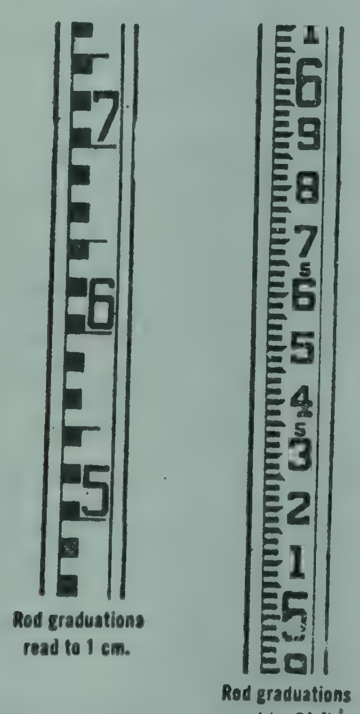


Figure 91 : Graduations of a Staff.

lines intercept a distance marked on the staff. The intercepted distance bears a fixed ratio to the horizontal distance between the telescope and the staff. This ratio is usually 1 : 100. So if the intercepted distance is 1 foot, the staff lies at a distance of 100 ft. from the telescope. As the additive constant of the telescope is about 1 foot, this 1 foot is also added to the horizontal distance making it 101 ft. Some of the telescopes have internal focussing system and hence the additive constant is less than 1 foot. It may vary from 4 to 8 inches.

THEODOLITE SURVEYING

The methods of plane surveying discussed so far, give techniques of measuring only horizontal distances. All of them are relatively simple. Now we come to the method which can be used for both horizontal and vertical measurements and which is the most complex and accurate among the methods discussed so far. It is called theodolite surveying. Theodolite is an instrument which can measure both horizontal and vertical angles and which has a telescope to facilitate the sighting of distant objects.

THEODOLITE AND ITS PARTS

There are two main types of theodolites: (1) transit theodolite, (2) non-transit theodolite.

A transit theodolite is one whose telescope can take a complete revolution about its horizontal axis in a vertical plane (fig. 92). It is the most commonly used theodolite.

1. *Trivate Stage:* It is the lower most triangular plate hinged to a tripod.
2. *Levelling Screws:* There are 3 or 4 screws fixed between trivate stage and the tribrach plate. In the case of a four screw iustrument, there is uneven distribution of pressure on the screws and consequently the wear of the screws is excessive. For stability, three points of support are sufficient. Besides, the three screw instruments can be more quickly levelled.
3. *Tribrach or upper parallel plate:* It is a triangular plate fixed above the levelling screws. It is also known as upper parallel plate.
4. *Spindles:* There are two conical spindles fixed one inside the other. They form the vertical axis of the transit· The inner spindle is attached to a vernier (upper horizontal) plate and the outer one to the lower horizontal plate.
5. *The lower horizontal plate:* The outer axis is attached to the lower plate also called the scale plate. Its edge or limb is silver plated

and graduated from 0° to 360° in a clockwise direction. The horizontal circle may be graduated in (1) degrees and halfs of a degree (2) degree and thirds of a degree, or (3) degrees and sixths of a degree, depending upon the size of the instrument. The lower horizontal plate is provided with (a) *A clamp*, and (b) *tangent or slow motion screw*, by means of which it can be fixed accurately at a desired position. When the clamp screw is tightened, the lower plate is fixed to the upper tribrach or parallel plate and on turning the *tangent screw*, the lower plate and the upper part of the instrument can be rotated slightly.

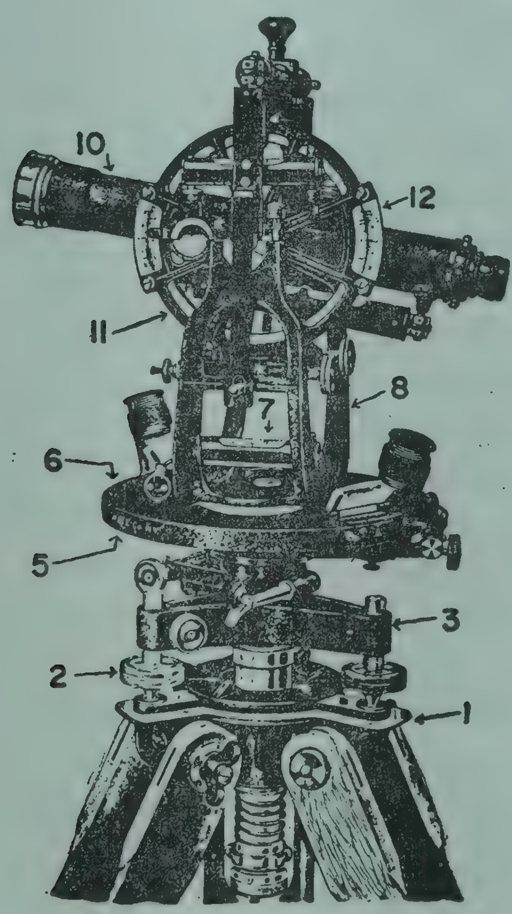


Figure 92 : Transit theodolite and its parts

6. *The Upper horizontal Plate :* The upper horizontal plate is also called the *vernier plate*:and is attached to the inner axis. A clamp and a tangent or slow motion screw are provided for the purpose of accurately fixing the vernier plate to the scale plate. This upper horizontal plate carries two verniers *A* and *B* with magnifiers placed 180° apart for reading horizontal angles to a minute or 20 seconds.

7. *Spirit levels:* Two spirit levels called plate levels placed at right angles to each other are fixed on the upper surface of the vernier plate for levelling the instrument.
8. *Standards:* There are two frames called standards to support the horizontal axis.
9. *Tube Compass:* The compass box may be either of tubular type or of a trough type. The former is mounted on the vernier plate between the standards, while the latter is either fixed below the lower plate, or screwed to one of the standards. This compass is used in directing the telescope towards the magnetic north.
10. *The Telescope:* The telescope is fixed at right angles to the horizontal axis. The telescope consists of (i) body, (ii) object glass, (iii) eye piece, (iv) diaphragm, and (v) focussing screw.
11. *The Vertical circle:* It is attached to the inner axis and is placed vertically. It has two verniers called C and D. It is graduated in four quadrants of 0 to 90° each. There are magnifiers to facilitate the reading of the scale. It is also provided with a clamp screw and a slow motion tangent screw. This plate, combined with the telescope of the theodolite, is called the alidade of the theodolite. It is used in measuring vertical angles.
12. *The Index Bar (or T. frame):* The index bar is T shaped and centred on the horizontal axis of the telescope in front of the vertical circle. It carries two verniers at the extremities of its horizontal arms or limbs, called the index arm. The vertical leg called the clipping arm is provided with a fork and two screws called clips or clipping screws at its lower extremity. The index arm and the clipping arm are together known as the T-frame. A long sensitive bubble tube is attached to the top of this frame. It can be centred by means of the clip-screws.

PROCEDURE

At the very outset, the instrument should be very carefully set on a tripod. It is absolutely necessary that the tripod should not have loose screws. If there is any loose contact in the joints, it will disturb the position of the instrument and lead to inaccurate work. The point-edges of the legs of the tripod should be firmly pressed into the ground.

Centering:

It means the fixing of the theodolite exactly over the required point on the ground. Hang the plumb-bob by the hook attached to the inner spindle.

The centering can be done by slightly moving any two of the legs of the tripod, so that the plumb-bob points directly to the ground station.

Levelling :

Bring the spirit level of the horizontal plate parallel to any two foot screws. Turn the foot screws until the bubble settles down in the centre. Turn the screws in such a way that the thumbs of both the hands move either outwards or inwards simultaneously. Then turn the instrument to let the level make an angle of 90° with its former position. Bring the bubble again in the centre by turning the third foot screw. Repeat the procedure twice or thrice to get an accurate levelling. Thereafter, clamp the lower plate and unclamp the upper plate. Turn the horizontal upper plate until 0° or 360° coincides with the vernier V. Clamp the upper plate also. Finer adjustment can be made with the help of the upper tangent screw. It may be pointed out, however, that such adjustment have to be made with reference to the vernier A. Unclamp the lower plate.

Reading the horizontal angles :

The horizontal angle is read with reference to the magnetic north. The magnetic north can be located with the help of the tubular compass attached to one of the standards. Turn the horizontal plate until the needle in the compass comes in between the lines of callimation.

Clamp the lower plate. Release the clamp of the upper plate. Turn the telescope in a clockwise direction towards the object. Sight the object and align it with the gun-sight. Clamp the telescope. By gently moving the eye piece focus the object, so that the cross wire coincides with the object. Now read the verniers A and B.

Reading the vernier scale is a bit ticklish. In figure 93 is shown a

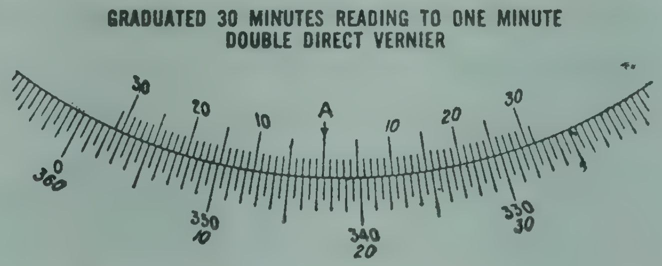


Figure : 93 **Reading angles with the help of a vernier scale**

vernier scale in which the zero of the vernier cuts the main scale at a point where the angle is more than 342° 30′ but less than 343°. To know the exact measurement of the angle, one should move along the vernier scale to the left

until one finds a vernier division coinciding with the main scale divison. The number of divisions one has to move from 0 gives that many parts of 1 degree which should be added to 342° 36′. In this case it is 5′, the required angle is 342° 35′. In some of the transits, angles can be read even up to 10 seconds.

Reading the Vertical angles :

Unclamp the lower plate. Bring the vertical spirit level parallel to any two foot screws. Turn the screws either outward on inward simultaneously, in order to bring the bubble in the centre of the spirit level. Now turn the spirit level 90° to the previous position. With the aid of the third foot screw, adjust the bubble. Repeat the procedure twice or thrice for accurate levelling. Now, let the 0 of the main scale conicide with 0 of the vernier scale in the vertical plate. Clamp the telescope. Move the telescope horizontally towards the object. Unclamp the telescope. Focus it at the foot of the object with the help of the eye piece. Read the angle both in C and D verniers. Now point the telescope to the top of the object and read the angle both in C and D verniers. If both the readings are above 0 or below 0, the first reading is to be subtracted from the second one in order to get the vertical angle. If one of the readings is below 0 and the other above 0, add both the readings to get the vertical angle.

Example :

I Reading 3° 10′ 20″ (foot of the object below zero)
II Reading 9° 10′ 20″ (top of the object above zero)

∴ Vertical angle : 12° 20′ 40″

I Reading 3° 10′ 20″ (above zero)
II Reading 40° 10′ 20″ (above zero)

∴ Vertical angle 37° 0′ 0″

An improved theodolite with operating controls designed for quick adjustment and focussing is shown in figure 94.

Plotting the results :

If the theodolite survey uses the triangulation method, we can plot the triangles either by computing the angles or the sides. The angular measurements made by theodolite are very precise. If one desires to find out the length of the sides, one should measure the base line and then get the measurements of other lines with the help of the following formula.

$$\frac{\text{Sin A}}{a} = \frac{\text{Sin B}}{b} = \frac{\text{Sin}}{c}$$

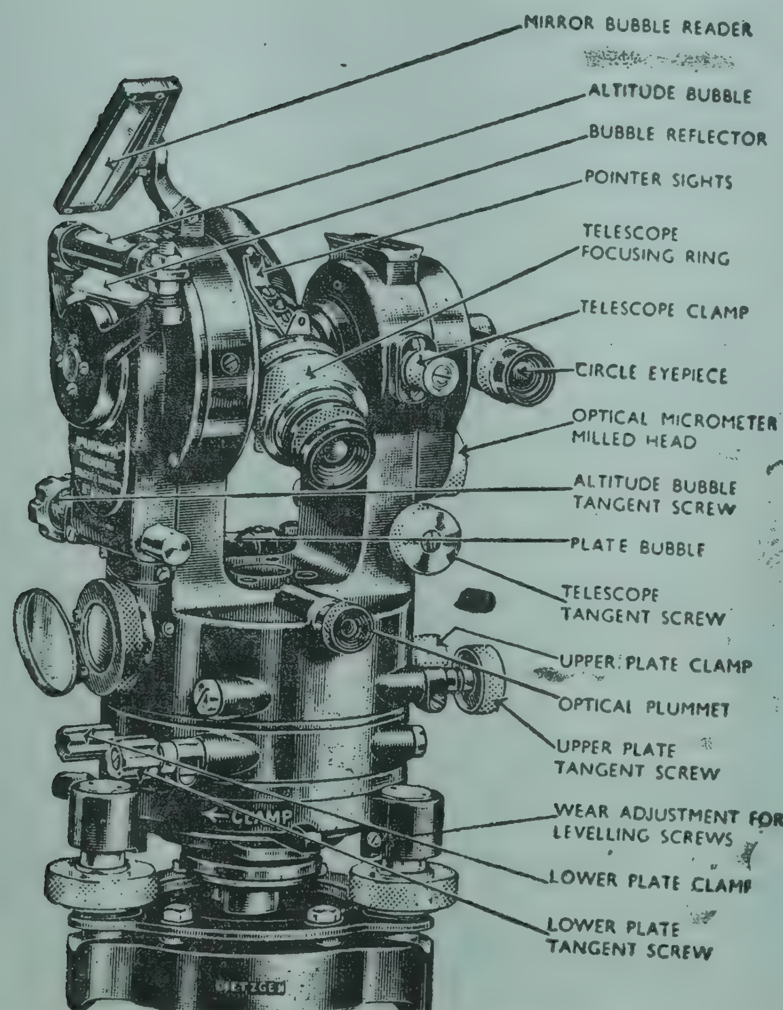


Figure 94: Watt's Microptic Theodolite

Where A, B and C are the three angles of the triangle and a, b and c the sides facing respective angles.

Verbally stated the sides of a triangle are proportional to the sin of the opposite angles. If we know one of the sides, we can know the other two sides also.

LEVELLING

Levelling is a process of determning the relative heights of various features with the help of an instrument called a 'level'. Earlier in this chapter some of the levelling techniques have already been explained. Further details of some of them are given here.

There are different kinds of levels. The ones which are in common use in India are (1) Wye-Level (fig. 95), (2) Dumpy Level (fig. 96), (3) Watt's High Way Level (fig. 97) and (4) Watt's Self-Adjusting level. Wye-level has its telescope standing on two standards whereas the telescope of the Dumpy level stands on a pivot. Both are easy to operate. The Watt's self-adjusting level

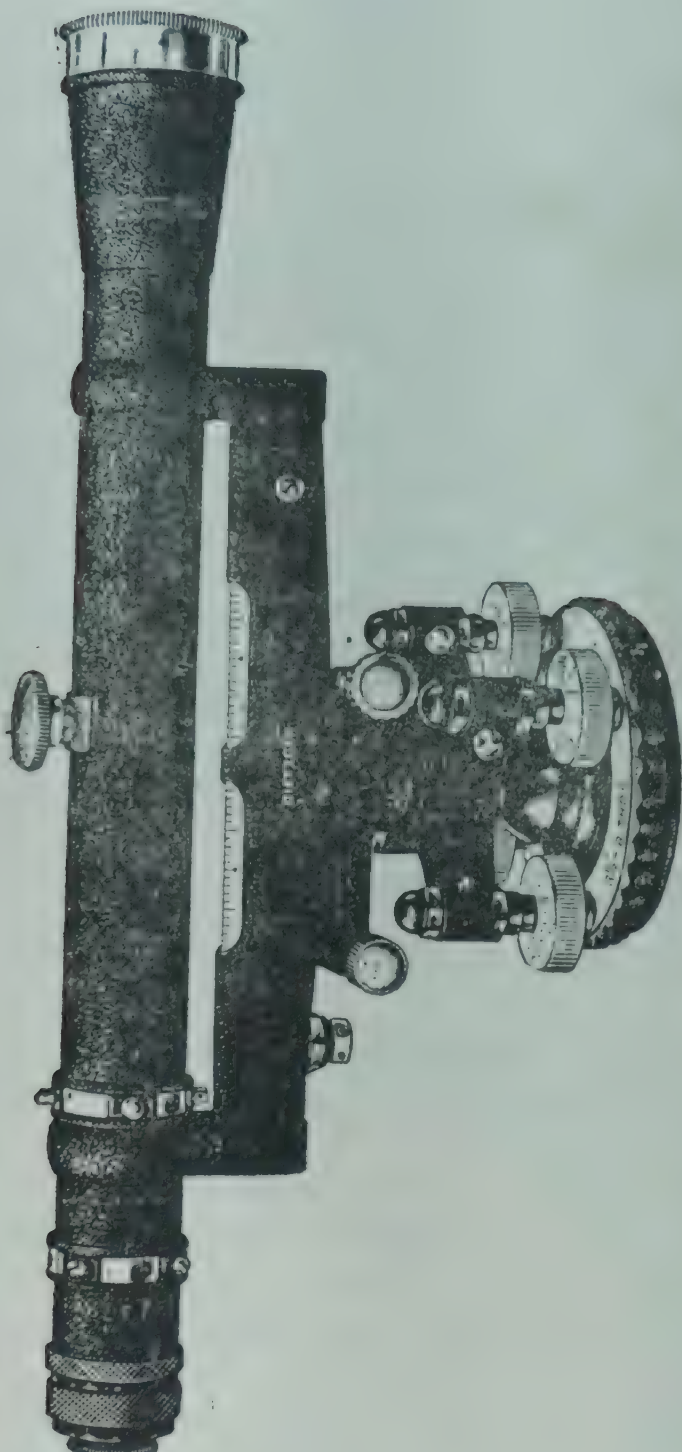


Fig. 95: Wye-Level

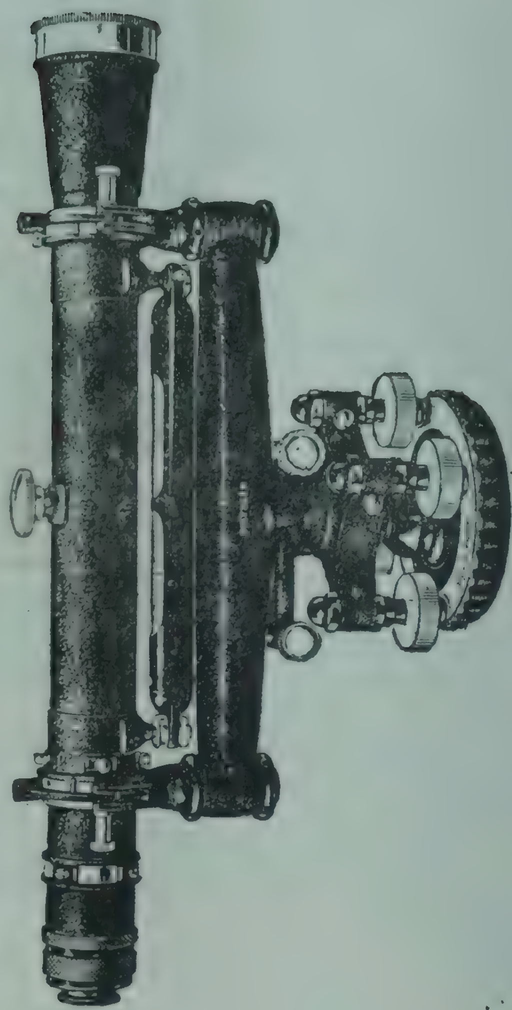
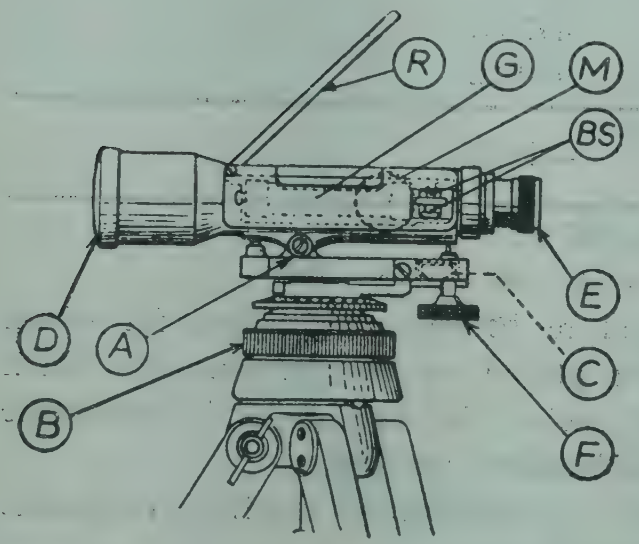


Fig. 96: Dumpy Level

is a simple modern reversible level. It has reflecting prisms which show the bubble and an index line. There are two mirrors to reflect light through the level tube. In this instrument, the telescope can be reversed through 180° about its longitudinal axis so as to bring the bubble on the right of the instrument.



A—Horizontal fulcram about which the telescope and its attachments rotate.
B—A bolt-and-socket jointed head used for primary levelling.
C—Air bubble
D—Ray shade
E—Eyepiece
F—Levelling screw
G—Air bubble attached to telescope
B—Copstan screws used for adjusting the air bubble
R—Mirror reflecting the bubble.

Fig. 97: Watt's Highway Level

Watt's Highway level:

The Watt's Highway Level is a very delicate and precise instrument. Its operational procedure is given below. After screwing the level to the tripod, centre it at a convenient place somewhere between the turning points (first two stations). With the help of the foot screws bring the bubble of the circular spirit level in the centre. Thereafter bring the main bubble in the mid-run. Focus the eye piece as well as the object glass. Direct the telescope toward the staff and clamp it. With the help of the slow motion tangent screw bring the image of the staff on the hair of the diaphragm. While reading the graduations on the staff it should be kept in mind that readings at the intersection of the cross-wires indicate backsight (or + s) of the starting point. For horizontal distances read the stadia. Then focus the telescope on the staff fixed at the second point. This time the reading will give the fore-sight (or—s). Noting these reading in the field book, we get the results as given below.

Point	Backsight +S	Foresight —S	Reduced level (R. L.)	Remarks
A	3 ft.		500 ft.	Point A has a Bench Mark giving height of 400 ft.
T.P. (B)	2 ft.	6 ft.	497 ft.	
T.P. (C)	4 ft.	5 ft.	494 ft.	
T.P. (D)	3 ft.	6 ft.	492 ft.	
E	—	5 ft.	490 ft.	
Arithmetical Check	12 ft.	22 ft.	—10 ft.	

(Calculation of RL. 500 + 3—6 = 497)

497 + 2 – 5 = 494 ; 494 + 4 – 6 = 492 + 3 – 5 = 490.

The levelling instrument is placed in between the points for which elevation has to be determined. It is not placed on the stations for which readings have to be taken. That is why seeing the first point is called the backsight reading and the next point the foresight reading.

The other type of levellings such as differential levelling or profile levelling use similar methods with slight variations.

Other levelling instruments :

There are a few simple instruments which are also used in measuring elevations. These are : (1) Abney level and (2) Indian Clinometer.

Abney level : It consists of a telescope attached to a protractor (fig. 98). The middle point of the protractor is marked by a zero. Both sides of the zero, graduations increase to 60° or 90°. Left side shows rise and right side

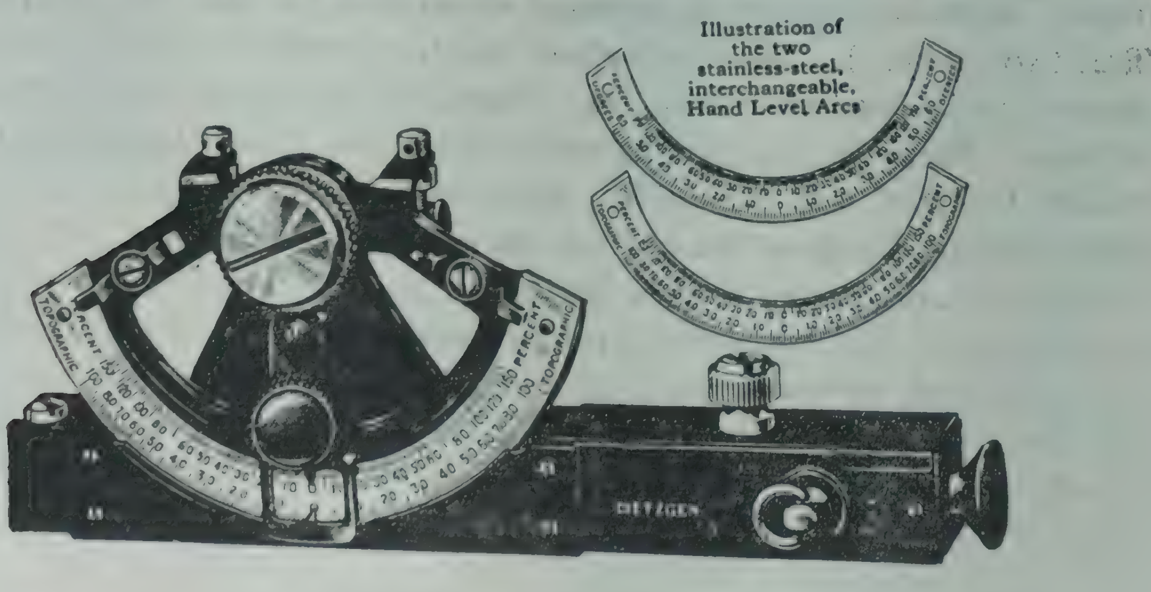


Figure 98 : Abney Level.

shows fall. The slopes are marked on the inner margin of the protractor. They are read by the vernier. A spirit bubble at the top keeps a check on the horizontal positioning of the level.

Indian Clinometer: It was developed by the Survey of India (fig. 99). It is used along with the plane table. It consists of a brass plate with an air bubble and two flaps at its ends. One of the flaps has a sighting hole and the other has a long slit and is graduated along both of its edges giving trignometric tangents and degrees of slope. In the middle is a common zero which is at the same horizontal level as the sighting hole.

1. Base plate
2. Levelling screw
3. Spirit level
4. Eye-Holes
5. Hinges
6. Stop
7. Collapsible struts

Figure 99: Indian Clinometer.

Determination of height with the help of an Indian Clinometer involves some arithmetical calculations. To determine the height of an object C from a point A in figure 100, the surveyour will go to the field with point B already marked. He will determine his position A by resection and then find out the ratio between bc and Ab by measuring the height of c. Suppose the ratio comes to $\frac{bc}{Ab} = .5$. As the slope of Ac is the same as that of AC, the ratio between BC and AB will also be the same. Since the map gives the horizontal distance AB and we know that $\frac{BC}{AB} = .5$. we can find out the length of Bc. This will give height of the object at C.

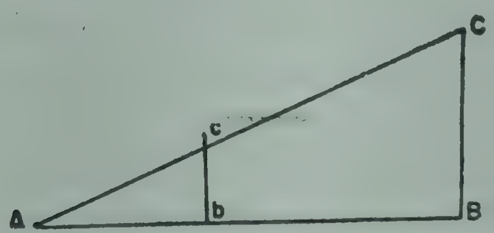


Figure 100: Measuring height with the help of Indian Clinometer.

HYDROGRAPHIC SURVEYING

Hydrographic surveying is the term applied to the processes used in surveying of water bodies. In the case of oceans or lakes this may include the determination of shore lines, soundings, characteristics of the bottom, location of buoys, etc. The survey of a river may also include the determination of the velocity and characteristics of the flow. In its broad sense the term may be applied to the survey of drainage areas and proposed reservoirs for the storage of water.

The surveys of shore lines of oceans, lakes and rivers are done in almost the same way as the land surveys. In addition to the instruments employed in land surveying, sextant is frequently used in hydrographic surveying. It is an instrument which, unlike the transit, is adapted to measuring angles in any plane. It is constructed in such a way that angles as large as 120 degrees can be measured. Owing to the fact that it can be used by an observer who is on a moving object, such as a boat, it is especially valuable for hydrographic work. Hydrographic surveys are also done with reference to the control points fixed by geodetic surveys.

The determination of the topography of the bottom of the sea, lake, or other bodies of water is one of the common problems in hydrographic surveying. Surveys of this kind are made for a variety of purposes, such as to prepare charts for navigation, to determine where dredged material may be dumped, or to measure the quantity removed. They are also done for the purposes of discovering what changes are taking place in the bed of the water body for scientific or constructional purposes.

This work is usually done by first establishing certain points on the shore (by triangulation or traverse) to which the hydrographic survey may be referred to, and then measuring, usually from a boat or hydrographic survey ship, the depth of the water at various points and determining the positions of these points. The measurements of depths are called soundings. Since the subaqueous surface is not visible, it is evident that for a given degree of accuracy a great many more points must be located to obtain the shape of the surface that would be necessary in an ordinary topographic survey of equal area.

CHAPTER X

AIR SURVEYING

The latest and by far the quickest method of surveying is air surveying. In air surveying, a camera is taken aloft in an aeroplane. The camera man takes photographs of the area to be surveyed. These photographs are then used to prepare maps of the area surveyed. The very fact that the aeroplane is not land-based while taking the photographs, makes this method most suited for surveying areas having rough and inaccessible terrain.

The vertical position of the camera obviously places it in a better position in relation to terrain features. It does not, however, mean that all the aerial photographs are without distortions and other blemishes. In fact, photographic distortions are just as inherent in aerial photography as in ground views. Objects directly beneath and closest to the lens are sharp and clear and those appearing near the margins are distorted. They often seem to lean away from their proper vertical orientation and their outlines are blurred and indistinct.

IDEAL CONDITIONS

The two conditions which must be satisfactorily met in aerial surveying are the favourable physical and mechanical conditions. The ideal physical conditions are, clear air and bright sun shine. Hygroscopic nuclei collect around smoke and dirt in the air to create a haze. A dust haze which is often found in relatively drier areas also affects the photographs because the camera picks up the dust particles as shades on the negatives. Clear air gives sharper prints. As will be explained later, shadows appearing on photographs give clues for the identification of features. Bright sunshine gives better shadows so necessary to photo interpretation. It must, however, be kept in view that with the help of some of the latest techniques now available, air photographs can be taken at night even.

The second condition which should be satisfactorily met is the proper functioning of the aircraft, the camera and the photographic materials used. Proper functioning of the camera obviously means that the proficient cameraman can expect to reproduce an image of high quality if the film is as good as his camera. If the air surveying is done in a war torn area and the plane is being shot at, the pilot cannot fly the plane at a constant level. The photos taken under such unstable conditions are not uniform in scale, tone and normal distortion. It is said that during the second world war 85 per cent of the photos had to be discarded.

PROCEDURE

The pilot has to have a flight map which guides his flight lines. A flight map gives the location of the points and area to be covered. If a flight map is not available, reconnaissance flights have to be made to get control points on the ground. For successful air surveying ground control points determined by geodetic surveying are essential. If such control points do not exist, survey parties may have to supply the necessary control before aerial operations begin.

As far as possible the flights should be flown along lines for which ground controls are in existence or which are marked by the presence of such prominent features like rivers, ridges or valleys. The most common pattern of flying for air photographs is called serpentine pattern. This pattern is shown in figure 101. The purpose behind this pattern is to make the flight lines overlap. Overlap is necessary to produce tie between adjacent photos. The side overlap is normally 30 per cent and the forward overlap is from 50 to 65 per cent. The side overlap ensures better lateral matching among flight strips whereas the forward overlap compensates for the optical inaccuracies on each photo and permits multiplex or stereoscopic interpretation of the photographs.

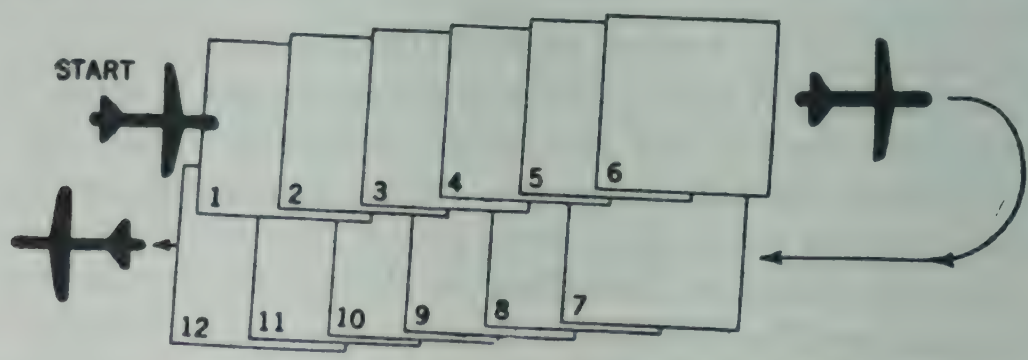


Figure 101 : Serpentine pattern of air surveying

SCALES OF PHOTOGRAPHS

The scale of the photograph taken from air is determined by the height at which the airplane is flown and the focal length of the camera. Here height means elevation above the ground, not above the sea level.

$$RF = \frac{\text{Focal length of the camera}}{\text{Altitude of the plane from the ground}} \text{ feet}$$

If the focal length is = 12 inches = 1 ft.
altitude above sea level = 11,000 ft.
elevation of the ground = 1,000 ft.

$$RF = \frac{1}{11{,}000-1{,}000} = \frac{1}{10{,}000} \text{ feet}$$

A photograph taken from a height of 10,000 ft. above the ground will have 1:10,000 scale (fig. 102).

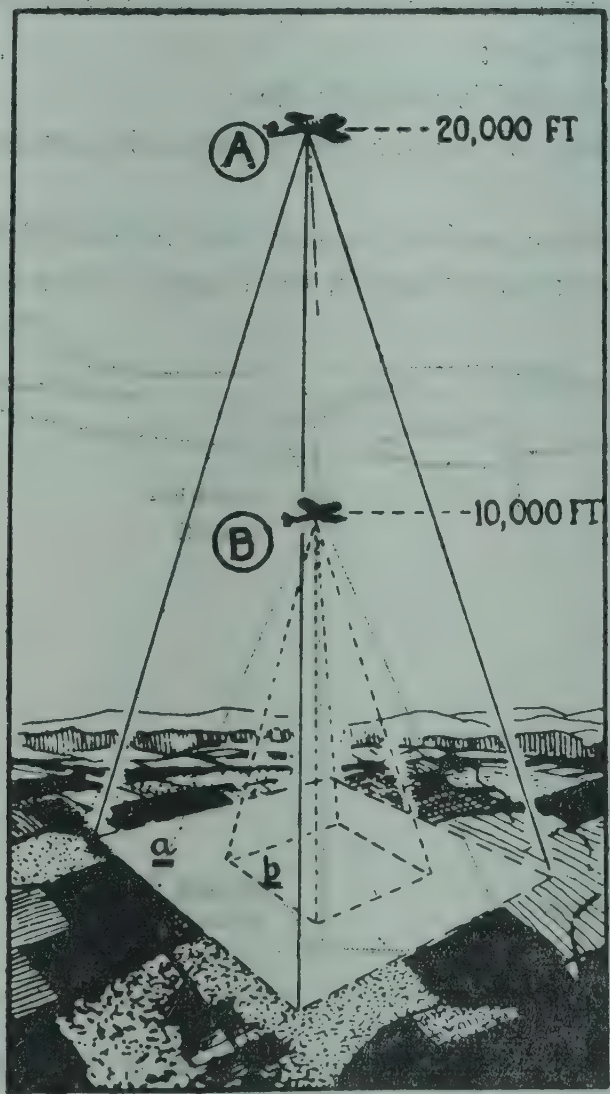


Figure 102: Effect of the height of the airplane above the ground on the scale of the photographs

An understanding of the scale makes it clear that higher the altitude of the plane greater the coverage of area in the photograph. But higher the altitude more difficult it is to define the features photographed.

CAMERAS

Several types of cameras are used in air photography. Some of them have fixed mountings while others have adjustable mountings. The cameras having fixed mountings cannot be adjusted to account for the change in the elevation or speed. Usually, at least three cameras are carried above the bomb bay of the plane. One of these is oriented to take vertical photographs while the other two are to take oblique photographs simultaneously.

SOURCES OF DISTORTION

An air photograph taken vertically can be substituted for a map if the following conditions are met:

1. area photographed is perfectly flat;
2. the focal plane of the aircraft is perfectly parallel to the surface of the ground, and
3. the camera has a perfect lense so that no lateral distortions occur.

These ideal conditions are met in the diagram shown in figure 103. But

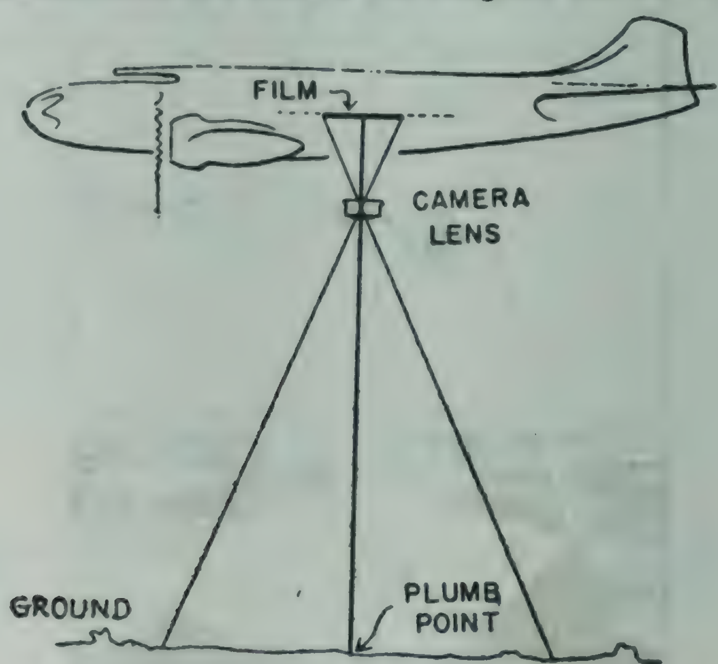


Figure 103 : Conditions under which distortions in the photograph are minimum.

such ideal conditions do not exist and, therefore, it is next to impossible to avoid distortions, except at and near the plumb point. Plumb point is the point where a plumb bob dropped from the air plane and through the centre of the film, touches the ground. Any feature in this alignment will be perfectly reproduced and the scale of the photograph will be true over its entire area. The distance between the centre of the film and any other point will bear the same distance relationship as distance between the plumb point and the

corresponding point on the ground. Since no earth surface is perfectly horizontal plane this relationship between the ground and the photograph is rarely observed.

The distortion introduced by ground relief is more properly called parallactic displacement or simply displacement. Parallax is an apparent change in the position of one object or point with respect to another when the two are viewed from different angles. When applied to aerial photography, it refers to the relative displacement of two points along the same line when viewed from an exposure point that is not directly overhead.

In figure 104, points (like Y) which are below V are displaced inward both in the negative NN′ and the positive PP′. Point Y′ will appear at y′ and not at y. Whereas a point like X′ which is above V or datum plane K k′ is displaced outward from x to x′. The total amount of displacement is directly proportional to terrain relief and to the distance from the plumb point and is inversely proportional to flight altitude.

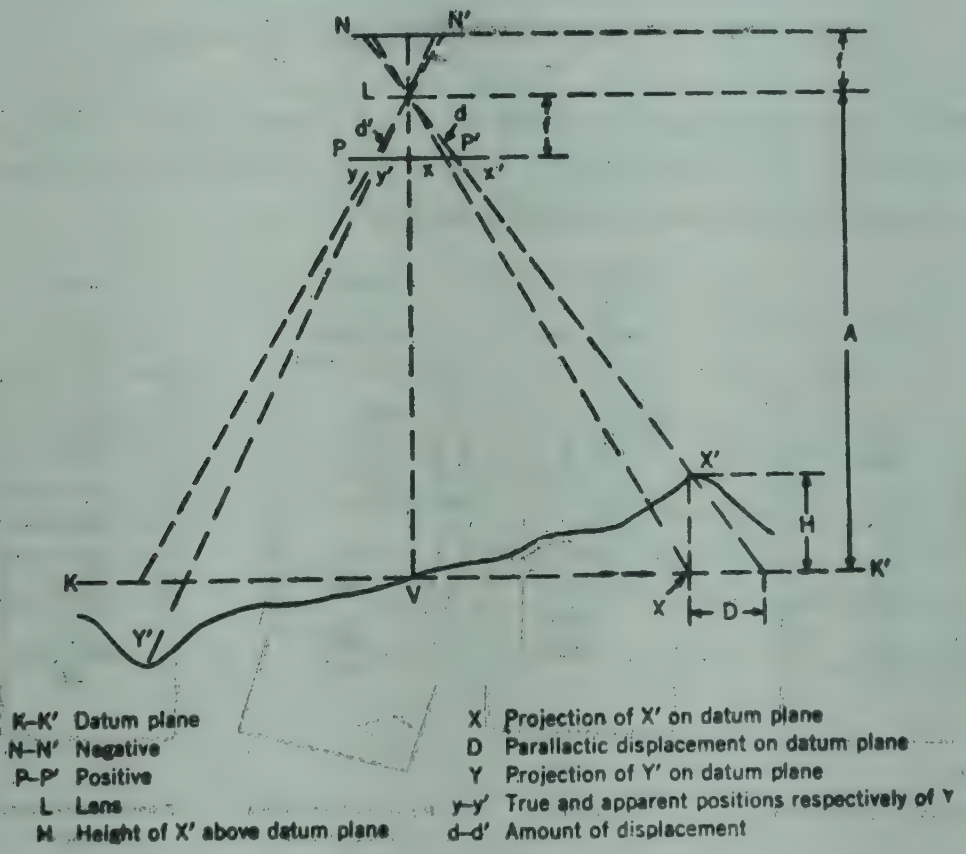


Figure 104: Distortions due to uneven terrain.

Because of the adverse weather conditions the air planes at times have to tip up or down the horizontal alignment. If the picture is being snapped at the time of the tip, it will show distortions. In case the air plane tilts to one

side, lateral displacements will take place. Such displacements are illustrated in figure 105.

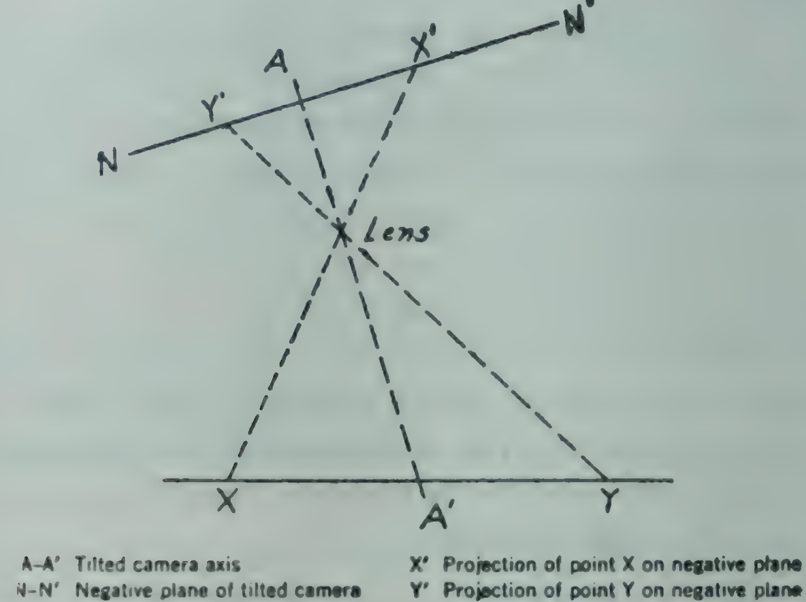


Figure 105: Distortions due to the tilting of the plane.

Crabing i.e. nudging of a plane by wind from its flight line also creates problems because the photographs taken under these conditions cannot be perfectly aligned in strips as illustrated in figure 106.

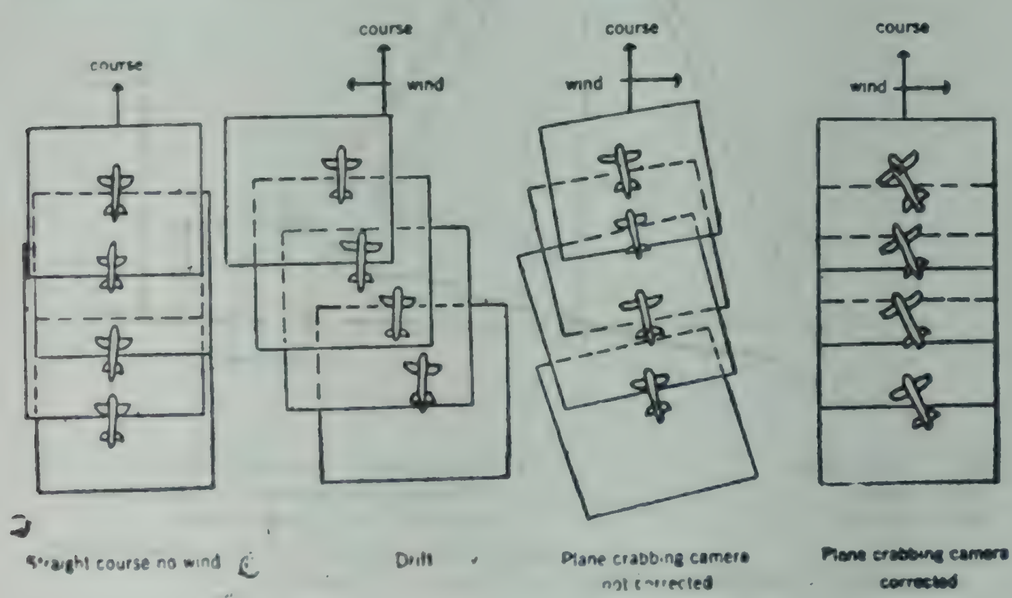


Figure 106: Other causes of distortion

PHOTOMOSAICS

The photographs taken from the airplane are rectified and any scale variations or distortions brought about by tip or tilt are corrected. The

rectified photographs are then joined together to give more extensive coverage. The overlapping pictures are cut along features like rivers where separation is least conspicuous. The prominent features can be named to facilitate orientation and identification. Such a mosaic can be used as the basis for the preparation of a map of the area photographed.

COMPILING MAPS FROM AIR PHOTOGRAPHS

Making maps from air photographs is a complex process. The science of photogrammetry deals with this process. We know that ground controls are essential for precise mapping. This applies to air photographs also. In an ideal case, there should be at least three geodetically determined and marked points on the ground in each air photograph. With the help of these three points the location of other points is determined. A base map, on a suitable scale and projection, is drawn for the purpose of plotting the points identified on the photographs. The points on the photograph are pinpricked or marked on transparent positives called diapositives. These are then positioned in a plotting machine and adjusted for scale, tilt, and other distortions until the points on the photograph and the map coincide. This is usually done on a sterioplotting machine. The details of the photographs can then be drawn on the map either directly or with the help of a pantograph.

STERIO-PLOTTING

A look at any air photograph shows that features likes houses, trees etc., seem to be leaning away from the centre. This is because only the centre of the picture has been photographed vertically. The marginal parts are distorted. This deficiency in an air photograph proves to be of great advantage in sterio-plotting. This is because the displacement of objects in two different pictures is not the same. If both the photographs are viewed through a sterioscope, we will get the mental image of a three dimensional model. The same principle underlies the process of sterio-plotting. A pair of positive prints is used in the relatively simple sterio-comparagraph ; diapositives are used in aero-cartograph, sterioplanigraphs, multiplex etc. In each case, photographs are positioned for steriographic viewing and mirrors, lenses, and prisms correct variations in scale, tilt etc. The operator sees the relief in a three dimensional shape. He focuses his instrument at a certain point. A flooting needle is made to move around the relief features. So long as he remains on the given elevation, he will see only one needle point. A pantograph attached to the plotter transfers the movement of the needle on a sheet of paper. This is the way a contour map is made out of air photographs.

CHARACTERISTICS OF AIR PHOTOGRAPHS

Air photographs, as we have already noted, give the eye view of the actual area photographed from above. They can be used in conjuction with maps of the area photographed to supplement the maps with the newest details. They can also be used as source materials for preparing new maps. The greatest advantage of air photography is the amount of details it gives at such a short notice. It is for this reason that it has acquired so much importance both for military and civil planning.

The effective use of an air photograph depends upon its correct interpretation. Air photographs have a far greater range of scenery possibilities than maps. Anything that appears on the landscape is reflected on the film. Often, this means too much details, or the obscuring of required details. Roads get lost under a canopy of foliage when leaves are thick upon the trees. Railroad tracks disappear into mountain sides. Houses appear reclining and not vertically errect. Heavy shadows mantle vegetation and many minor details and thus confuse the patterns made by man and nature. Such confusion can be considerably reduced by scientific interpretation of air photographs.

TYPES OF AIR PHOTOGRAPHS

There are five types of air photographs :

Vertical photographs :

These photographs are taken with an air-borne camera aimed vertically downward from the plane ; the axis of the camera is perpendicular to the ground surface. This provides a photograph that is parallel to the ground below.

Oblique photographs :

These photographs have their axes purposely tilted from the vertical. The amount of tilt varies from 30 to 60 degrees. An oblique photograph showing the horizon is called a high oblique, One which does not have the horizon showing is called a low oblique. Oblique photographs, because of the side-view characteristic they possess, produce a more normal view of ground objects. Oblique photographs help in studying the terrain or ground features having considerable relative relief such as tall structures or slopes.

Composite photographs :

These photographs are printed from three or more separate negatives which are exposed simultaneously by a multilens camera. The multilens camera of usual construction has one lens aimed along a vertical line of sight

and other lenses arranged in pairs tilted away from and on opposite sides of the central lens. When printed, the tilt is reversed and the resulting photograph is all in one piece and in the same plane as the portion exposed by the central lens. These photographs cover large areas. With the development of wide angle cameras capable of covering equally large areas, the importence of multilens cameras has now declined.

Timetrogon photograph :

Timetrogon photograph is the result of the combination of three separate photographs exposed simultaneously by three single lens cameras mounted in the same air plane. The central camera takes vertical photographs while the other two take oblique photographs to the right and left of the line of flight. The cameras are so fixed that the entire area from right horizon to the left horizon is photographed. The coverage is not printed as a composite photograph.

Sonne' photograph :

These photographs are parts of a continuous strip of terrain. This is done by allowing the negative to move continuously over a fixed slit. The speed of the movement of film across the slit is adjusted to the speed and height of the aircraft.

IDENTIFICATION OF AIR PHOTOGRAPHS

Like maps, air photographs in their finished form possess certain indentification marks. These marks are also called marginal information or data. They include time, date, camera type, altitude and other pertinent facts. But all these details are not given on all air photographs. Each photograph is also given an index number which gives ready access to the photograph. The indexing is done with the help of a map on which the available photographs are serially positioned. The index numbers are given either at the point where the centre of the photograph falls or on one of the sides of the area covered.

DETERMINATION OF DIRECTIONS ON AIR PHOTOGRAPHS

To make the best and correct use of an air photograph it must be oriented like a map with north at the top. If a comparable map of the area photographed is available, the direction can be determined by comparing the location of some common features. If the time of the photograph and the latitude of the area covered are known, the directions can be found out with the help of the shadows on the photographs. In the temperate zone of the northern hemisphere, for example, the rays of the morning sun will cast

shadows to the noth-west, the evening sun, to the north-east and the noon sun to the true north. In the southern hemisphere the directions will be just the opposite. The method is illustrated in figure 107.

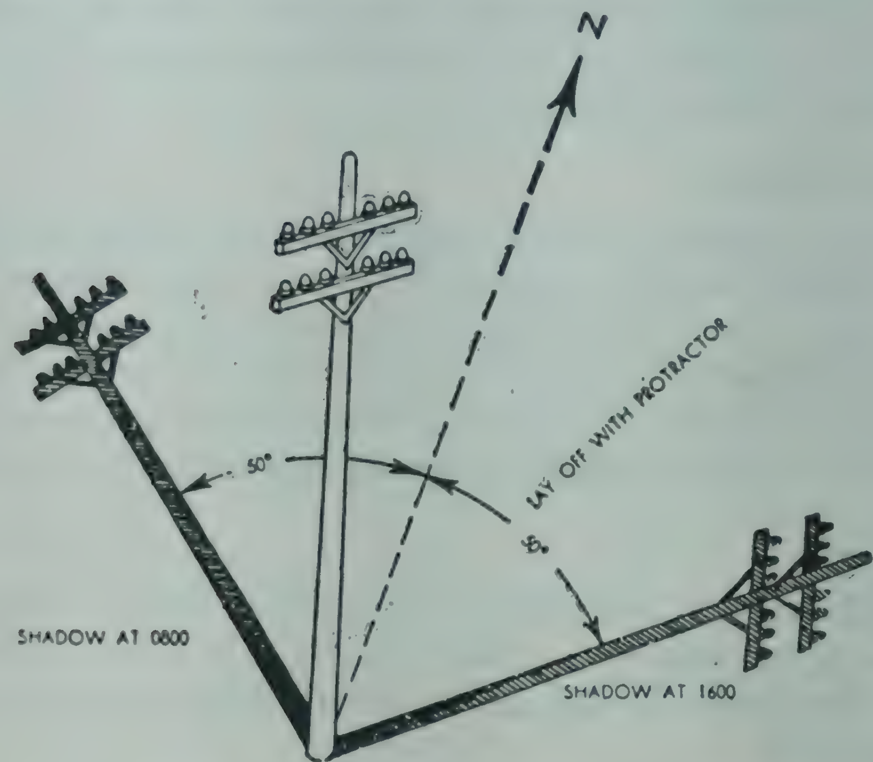


Figure 107 : Determining the north with the help of shadows cast by the feature photographed.

AIR PHOTO INTERPRETATION

There are certain clues which help in interpreting the air photographs.

Size :

The relative size of the images on the photographs help in identifying them. For example, the residential buildings are more likely to be smaller than the industrial and commercial ones. Similarly, the size of the farms suggests not only the degree of fragmentation of holdings but also the landuse intensity. One can also distinguish the courts and fields used in various games.

Shape :

Usually the regular shaped features are man-made such as roads, canals and railway lines whereas the irregular shaped features are natural such as rivers, forested areas etc. The cultivated fields tend to have well-defined regular shapes whereas shorelines and small water bodies are usually irregular in shape.

Tone or Shade :

Shades of gray on the photograph is also very useful in interpretation. Tone of the photograph depends entirely upon how much light is reflected back to the film. In general, air photographs portray light coloured objects in light gray and darker objects in darker images. Forest areas and deep water appear dark whereas concrete pavements and shiny roofs show up light gray. Muddy water appears lighter. Grass appears medium gray and sand appears as white.

Texture :

The pattern of the surface features as apparent from the photographs tells much about the surface details. The ploughed land looks streaked and even-textured ; pastures look smooth with spots ; bushes look finely mottled and forest coarsly mottled. The orchards show up as closely and evenly set large spots.

Shadows :

Shadows help in estimating the height of objects. To see the relief, the picture should be turned around so that the shadows fall toward us. If they fall away from us, we will see a reversed relief so that mountain range will appear as a valley.

Surroundings :

At times the existence of certain features can be guessed from other visible details. Many relatively small houses or ammunition dumps can be discovered by path or approach roads leading to them. This technique acquires considerable significance in military operations for the location of military buildings are comouflaged. Similar principles are applied to determine the location of schools and colleges. A large building with white ground around indicates the location of a school.

Seasonal Variations :

The above generalities can lead to wrong interpretation of air photographs if the time of the day and the season in which the particular photogragh was taken is not kept in view. Air photographs mirror the changing mood of each season and each hour of the day. Skilled photo interpreters check the date and time of exposure as soon as they receive the prints. In a deciduous area the leaf and grass coverage will vary with season. Similarly an intermittent stream shows different patterns in different seasons. After the

heavy rains, the stream will appear wide but during the dry periods it shows up only as a narrow trickle.

STERIOSCOPIC VIEW

Looking at the images of a features shot from two different angles gives what we call a sterio view or three dimensional view. We have noted how air photography enables each point on the ground to appear at least in two photographs. All air photographs have the characteristics of sterioscopic view. Viewing two air photographs sterioscopically gives the same view of the ground as one will get while looking down from a plane. This enables the user to see the ground more realistically, and this is one invaluable asset which air photograph possess.

The two overlapping photographs required for sterioviewing are called sterio pair and are so placed for study that they are in the same relative positions in which they were taken. The left eye sees one and the right eye the other photograph. The overlapping ground in the centre is seen by both the eyes simultaneously.

Sterioscope is the instrument to be used in sterio-viewing. The photographs (sterio-pairs) are placed beneath the sterioscope in such a way that the details under the two lenses are indentical. If the photos are placed correctly, the images will merge into one giving a three-dimensional effect.

USE OF AIR PHOTOGRAPHS

A set of good air photographs can save hours of reference reading and produce a clearer impression of the ground detail than what a map can give. It can also increase the value of a physically reliable but culturally obsolete map, when used in conjuction with a map. In the present day dynamic world, the cultural features change too frequently to be subjected to mapping. Mapping is a time consuming and costly affair. It is not possible to prepare new topographic maps of an area, say, every year. Such changes are, however, more common in certain areas than in certain others. The interpreter can better interpret air photographs if he knows the areas where changes can be expected most. Aerial photography can prove to be the most effective and readily available source of new or supplementary data.

A knowledge of physiography, geomorphology and geology of the area photographed helps in interpreting the physical details. For example, we will not be alarmed to find violent changes in the natural landscape of an area, if we know that it is susceptible to earth quakes. A note of caution may be underlined here. All differences between features shown on a map and on a

photograph of the same area should not be ascribed to changes in the natural or cultural landscapes. At times a wrong interpretation of air photograph may be the cause of apparent disparities while at others the faulty compilation of the map may be the cause. It may also be added in this regard that even the most skilled photo specialists using the latest photographs and photogrametric equipment cannot always identify and interpret every detail appearing in a photograph. Unique features and cultural peculiarities the world over impose problems which cannot be solved by air photographs alone. A sound knowledge of geography of the area photographed is, therefore, essential for correct interpretation of air photographs.

CHAPTER XI

CARTOGRAPHIC COVERAGE OF THE WORLD

Undoubtedly, the most important source of map data are the topographical sheets published by various government agencies the world over. These maps are based on original surveys and are by far the most authentic in matters of accuracy. These are large scale maps and hence give a variety of physical and cultural data in relation to each other. The small scale maps of both general and thematic types, are compiled partly from these maps and partly from other sources. In all cases, however, these maps are the only sources for facts on the shape and size of the area, longitudes, latitudes, relief, contours, water features, mineral resources and population centres.

Topographical maps also form the base for the maps used by the armed forces. Quite many of the military failures can easily be traced to inadequate topographic mapping. The lack of such maps puts a country in a disadvantageous position with regard to both civil and military planning.

Topographic mapping is not uniform the world over. Certain areas have very good coverage whereas certain others lack even elementary maps. The cartographic coverage of an area depends upon its economic stage of development and local strategic importance for either peace or war time activities. For example, an effort to cover the whole of the Amazon basin by large scale detailed map series may not be desirable because the cost involved will be too high and the potential benefits from it too small. As against this, a large scale series coverage of say Damodar valley or NEFA in India is so essential that the cost involved is minor in comparison to the benefits derived from it. We need such maps of Damodar valley for civil planning and of NEFA for military planning.

Unfortunately many countries of the world have not given adequate attention to topographic mapping. This attitude underwent change only after

these countries lost hundreds of rupees for each rupee saved by not undertaking topographic mapping. As apparent from figure 108 so far a large part of the world is very poorly mapped. It is more so in the underdeveloped areas where large scale maps are desperately needed for developmental planning.

(a)

(b)

Figure 108 : (a) World map showing areas covered by 1 inch to 1 mile topographical mapping ;
(b) Map of the world showing air photo coverage. Both the maps are highly generalized.

INDIA AND ADJACENT COUNTRIES

Much of the topographic mapping of south-west and south-east Asia and almost all of the basic geodetic framework were developed and accomplished by the Survey of India. No other single agency in the world has covered larger area by original surveying and mapping than the Survey of India has done. The beginning of the Survey of India can be traced to 1767 when Major James Rennell was appointed the first Surveyor General of Bengal. Rennell's famous 'Map of Hindoostan' produced in 1788 marks the beginning of the history of scientific mapping in the country.

Initially the survey work was carried out independently in the three presidencies of Bombay, Madras and Bengal. Accurate mapping through triangulation survey was adopted only after the appointment of Colonel William Lanbton in the beginning of the 19th century. His successor Sir George Everest introduced several changes and improvements in the triangulation survey.

The Survey of India gradually spread a system of primary triangulation over a large area having considerable variations in terrain, climate, natural vegetation and human activities. The whole area was surveyed with respect to a single datum point and plane. This foresight avoided the confusion that developed in many other parts of the world where piece-meal work preceded an overall triangulation network.

In addition to the development of a single triangulation net covering a large area, the Survey of India was also responsible for precise level nets, magnetic surveys, gravimetric computations and for land analyses of agricultural and economic projects and cadastral surveys. Most of the maps produced by the Survey of India are based on plane table surveys tied to the geodetic triangulation network.

With the partition of India in 1947 and the separation of Burma and Ceylon from British India earlier, the Survey of India is now responsible for detailed mapping of India, Nepal, Bhutan and Sikkim only. It produces maps of 1 : 1 million, quarter inch and one inch series. At present it is engaged in revising the old sheets, preparing detailed maps for developmental projects and in conducting aerial and other surveys in such strategic areas as Sino-Indian border. The head quarters of the Survey of India are at Dehradun. Its regional offices are located at Bangalore, Calcutta and Abu.

A sister organization known as Directorate of Military Survey is located at New Delhi. During the Second World War it was a British organization responsible for Allied mapping of South-East Asia. At present it is engaged in preparing maps suitable for military purposes. With few exceptions, the series

of maps it produces are revised copies or reprints of the Survey of India maps, with added military details. Its Hind series covers countries like Thailand, Burma, Malaysia, India, Pakistan and Indonesia. Navigational charts are prepared by The Naval Hydrographic office.

A new organization called National Atlas Organisation was set up in 1956 to prepare a National Atlas of India. This Organization has produced a number of thematic and general purpose maps on scales ranging from 1 : 1,000,000 to 1 : 10,000,000. The base maps for these maps have been derived from large scale topographical sheets produced by the Survey of India. The thematic data have been superimposed to produce creditable cartographic results. Cartographers having problems of showing too much of information on relatively small and medium scale maps, will be well advised to look into some of these maps.

The organizations responsible for topographic mapping in some of the South-east Asian Countries are Survey of Malaysia in Malaysia, Survey of Burma in Burma, the Royal Survey Department in Thailand and Survey of Pakistan in Pakistan. In Indonesia the Indonesian Army Topogrphic Service is responsible for the large scale mapping of the country.

Types of Maps :

The Survey of India publishes its maps in a number of series. These are :

Topographical maps : Under this series topographic maps on following scales have been published :

1″ = 1 mile i.e. 1 : 63,360

1″ = 2 miles i.e. 1 : 1,26,720

1″ = 4 miles i.e. 1 : 2,53,440

India and Adjacent Countries : Maps of India and adjoining countries on the scale of 1 : 1,000,000 come in this series. Each sheet covers an area 4° latitude 4° longitude. Although this series has now been replaced by Carle International du Monde, it continues to remain important, because it is on this basis that India has been divided into 4×4 degree sheets.

Carle International du Monde Series : To fall in line with other countries of the world and in consonance with International agreements, the Survey of India has published on the International projection, maps of India in sheets. Each sheet consists of 4° of latitude of 6° of longitude. The scale of this series is also 1 : 1000,000.

Southern Asia series : Maps of South Asia comprising of the whole or parts of Iran, Afghanistan, Yemen, South Yemen, Soudi Arabia, etc., China, India, Burma, Vietnams, Cambodia Laos, Thailand and Singapore. The scale of

these maps is 1 : 2000,000. Each sheet consists of 8° of latitude and 12° of longitude.

Guide maps of Towns : Maps of a number of important cities on scales ranging from 3″ to a mile to 6″ to a mile have been issued.

Identification of sheets :

As stated earlier the numbering of Survey of India sheets is based on the series called India And The Adjacent Countries. Each sheet of this series covers 4° of longitudes. In all there are 136 sheets covering India and adjacent countries. These sheets bear numbers like 1, 2, 3 . . . 136. These are known as index numbers.

The 1 : 1000,000 sheets are sub-divided into 16 parts, each part extending over 1 degree of latitude and 1 degree of longitude. Each of these sub-divisions forms a 1″ = 4 miles topographical sheet. These sheets are indexed in letters A to P. To enable one to find out the million sheet to which a particular quarter inch sheet belongs, the letters are preceded by the index number of the million sheet. So that 64 P means the quarter inch sheet belonging to the 16th 1° latitude and 1° longitude quadrangle of the million sheet number 64. A quarter inch sheet is also called a degree sheet because it extends over 1° of latitude and 1° longitude.

Each of the quarter inch sheets is further sub-divided into four half inch sheets. These sheets are on the scale of 1″ = 2 miles. The indexing of these sheets is based on the direction in which they are located in the quarter inch sheet. These index marks are preceded by the index numbers of the quarter inch sheet to which they belong. So that the first sheet of 53 J will be designated as $53\frac{J}{NW}$. The qurter inch sheets are also divided into 16 parts to give what we call one inch sheets. These sheets are made on the scale 1″ = 1 mile and are indexed from 1 to 16. These numbers are preceded by the index marks of the quarter inch sheet to which they belong. So that the last one-inch sheet of the quarter inch sheet 76 P will be called $76\frac{P}{16}$. Some of the conventional signs used in the topographical maps of the Survey of India are shown in figure 109. With the introduction of the metric system of measures the Survey of India has now started a new series of topographical maps on 1 : 50,000 scale.

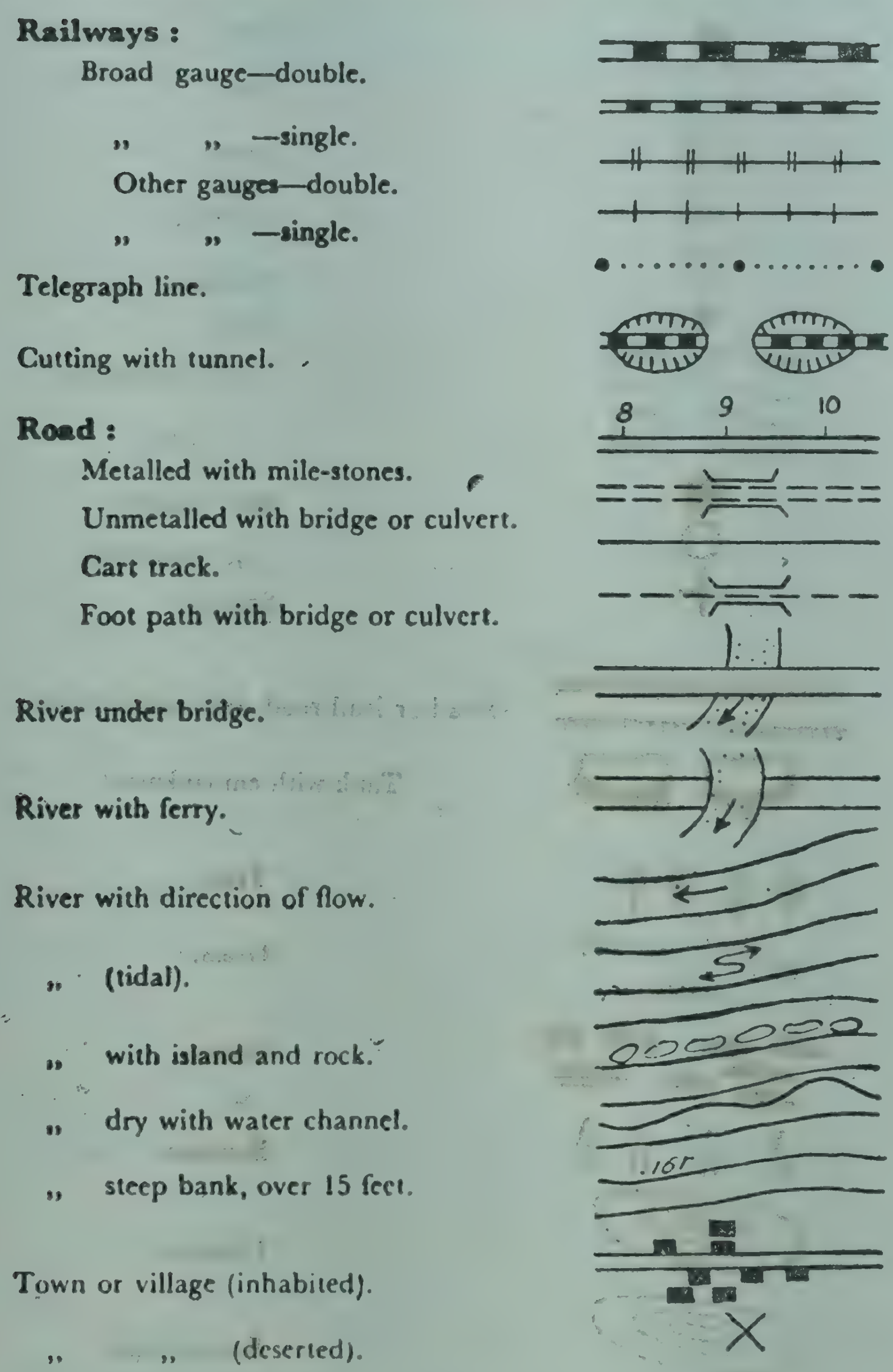


Figure 109 : Some of the conventional signs and symbols used by the Survey of India

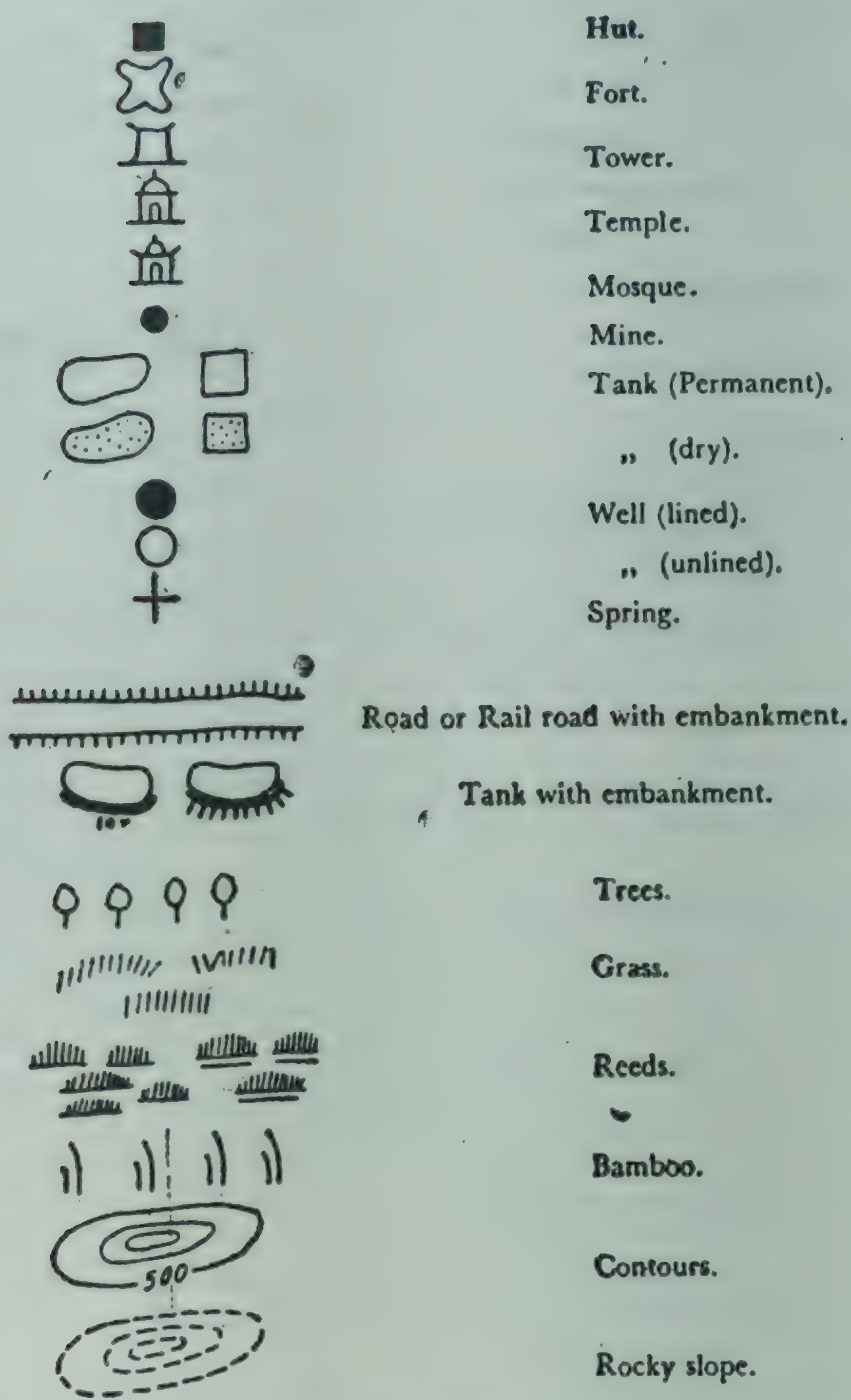


Figure 109: Some of the conventional signs and symbols used by the Survey of India

Heights (triangulated) :	
Station.	△ 200
Point.	● 200
Approximate.	. 200
Bench mark :	
Geodetic.	BM 200
Canal.	● 200
Other.	. 200
Post Office.	PO
Telegraph Office.	TO
Combined Office.	PTO
Police Station.	PS
Dak Bungalow.	•DB
Inspection Bungalow.	IB
Rest House.	RH (Forest)
Circuit House.	CH
Reserve Forest.	RF
Protected Forest.	PF
Boundary :	
International.	—— • —— • —— • ——
State (Demarcated).	—— · —— · —— · ——
,, (Undemarcated).	——x——x——x——
District.	– – – – – – – – – –
Forest.	·· ·· ·· ·· ·· ··
Boundary Pillar :	
Surveyed.	▤
Unsurveyed.	□

Figure 109 : Some of the conventional signs and symbols used by the Survey of India

CHINA AND JAPAN

Topographic mapping in China began sometimes between 1708 and 1718 when a group of Jesuit fathers carried out a survey of China on the request of emperor Hsu. The maps prepared during this period were in use until very recently. Early in this century the central land survey board in Peiping started plane table surveys. The maps produced by this organization were better than the Jesuit maps. In 1946, this organization was called Bureau of Survey, Ministry of National Defence. With the coming of the communist regime, the survey and mapping programmes have been stepped up.

In Japan, modern topographic surveying began in 1875, although the coasts of the country were surveyed much earlier. The Japanese Imperial Land Survey Bureau was established in 1888 as the official cartographic agency of the country. By 1925, the main islands of Japan were surveyed and mapped on 1 : 50,000 scale. These maps contained a uniform contour interval of 20 meters based upon Tokyo datum. Later this programme was extended to cover Korea, Karafuto, Kuriles, Ryukyu and Taiwan. During the Second World War the Japanese carried out original surveying and mapping in Indonesia, New Guinea, the Phillippine Islands and several smaller islands in the Pacific Ocean. In 1948, the Geographical Survey Institute was established as the official mapping agency of the country.

THE USSR

In the USSR, large scale topographic mapping was confined to the European Russia until the 1917 revolution. It was based on the Pulkova central meridian passing through 30° 19′ 36″. The surveys were inadequate and the maps were inferior. After 1917, the General Staff, Red Army, in conjuction with the Chief Administration of Geodesy and Cartography and the Chief Aero-Geodetic Administration, was made responsible for official mapping. The maps prepared by these agencies are useful for military as well as administrative and planning purposes. By 1950 major portion of Siberia was covered by accurate surveys. In recent years considerable progress has been made in aerosurveying and cartographic coverage in general.

AFRICA

The cartographic coverage of Africa is spotty and uncoordinated. The core and economically important areas of various countries are covered by some sort of mapping but vast intervening areas are either partly or completely unmapped. The best mapped areas of Africa are its northern and the southern parts. Some excellent quality mapping projects were undertaken and

completed by the French, Spanish, Italians, British and the Germans. The quality of coverage in central and interior Africa is generally poor. Only parts of former Belgian Congo are mapped. But the mining areas have been well mapped. Similarly the British mapped parts of their East African territories. At present the national governments in most of the countries of Africa are trying to have a complete cartographic coverage of their territories as early as possible. The situation in southern part of Africa is also not very good except in the Republic of South Africa.

GREAT BRITAIN

The beginning of topographic mapping in Great Britain can be traced back to the Highland Rebellion of 1745. It was then felt that coordinate planning, surveys and mapping were necessary to strengthen the unification and defence of the islands. The Ordenance Survey was constituted in 1791 and was charged with the responsibility of making a map of Great Britain on the scale of one inch to a mile. It established triangulation networks and developed large scale map series covering all the British Islands. The present large scale survey and continuous revision of existing series together with the Land Utilization Survey maps provide perhaps the best map coverage of any country in the world.

Since 1943, the Directorate of Military Survey is responsible for military topographic maps. It also prepares aeronautical charts for the Royal Air Force. A third organization called Colonial Surveys is responsible for surveys in the British colonies.

FRANCE

Institut Geographique National, a civilian organization, used to be resposible for topographic mapping in France. In 1940, this institute was, however, replaced by the Service Geographique de l'Armee. Among its many responsibilities are the geodetic and other surveys and the supply of strategic and operational maps to the French General Staff. It also serves the French overseas colonies and some of the former colonies in Africa.

GERMANY

Prior to the First World War, topographic mapping in Germany was done by the military. After the war *Reich Sampt fur Landesaufnahme*, a civilian organization, was given this responsibility. After the Second World War all mapping works were entrusted to *Landesvermussungsampt* of each constituent state of West Germany. At present these regional offices and the *Institue fur*

Angewandte Geodasic (Institute for Applied Geodesy) are collectively responsible for mapping in the Federal Republic of Germany. In the German Democratic Republic five regional offices called *Ver messungsdient* are responsible for mapping.

OTHER EUROPEAN COUNTRIES

The following are the official mapping agencies in other West European Countries:

Italy—*Instituto Geografico Militare*

Spain—*Institute Geograralco catastfi Estadistico and Servicio Geografico del Ejercito.*

Switzerland—Confederate topograhic office and confederate survey Administration.

Belgium—*Institut Geographique Militaire*

Netherlands—*Dutch topografische Dienst*

Norway—Norweigian Geographic Survey

Sweden—*Rikets All-manna Kartverk* (RAK) (National Mapwork Service).

THE U. S. A.

Need for accurate topographic surveying and mapping was felt acutely in the U. S. A. during and after the Civil War in 1860. In the absence of accurate maps, the westword movement of the people could not be planned, nor could the natural resources of the country be properly tapped. The civil war campaigns also proved beyond doubt that accurate maps were necessary for national defence and integrity. In 1878 the U S Geological Survey was constituted. It sent out field parties to establish control points, to compile topographic maps, and to collect other source materials concerning the geologic and topographic features of the country. This organization continues to be the main mapping agency in the United States.

The US Coast and Geodetic Survey was started in 1878, although a small unit of it was commissioned as early as 1807. It determined control data such as mean sea level, North American Datum and extended primary triangulation and levelling networks from these bases. It collects tidal current and coastal data needed for navigation and publishes coast pilots, tide tables, hydrographic charts, and aeronautical charts. It also makes magnetic observations.

The other mapping agencies in the U.S.A. are (1) Naval Hydrographic office, (2) Aeronautical Chart and Information Service, (3) Corps of Engineers, and (4) The Army Map Service.

CANADA

Topographic mapping in Canada has been slow and spotty until very recently. The large extent of the country with vast expanse of sparse and uninhabited forests, rocky uplands and snow covered areas made an extensive mapping programmé a difficult venture in the past. But these very handicaps have brought Canadians into prominence in the most modern method of mapping i.e. aerial surveying and photogrammetry. As a matter of fact, the method of mapping from oblique photographs was developed in Canada. The method is commonly known as trimetrogon technique. It uses a camera which can take one vertical and two oblique photographs simultaneously.

At present almost the whole of Canada is covered by maps on the scale of one inch to four miles. But the coverage on one inch to a mile scale is still spotty and limited to St. Lawrence Valley and mining areas.

The chief official agency responsible for topographic mapping in Canada is the Department of Mines and Technical Surveys. It has two branches (1) Survey and Mapping Branch, and (2) Topographic Survey Division. The Army Survey Establishment caters to the map requirements of the armed forces.

LATIN AMERICA

Topographic mapping of major portion of Latin America is still poor and fragmentary. For many areas, the 1 : 1 m. series produced by the American Geographical Society is the only coverage. The series was completed in 1945. It has 107 sheets.

After the Second World War a number of Latin American Governments took keen interest in starting, reliable mapping programmes in their respective countries. Aerial Surveying has now covered major portion of these countries but the progress in mapping has been slow. Argentina, Brazil, Venezuela, Mexico and Columbia have been progressing fast in this direction.

CHAPTER XII

INTERPRETATION OF TOPOGRAPHICAL AND GEOLOGICAL MAPS

We can learn a lot about the nature of the area mapped from carefully prepared topographical maps. To make an effective and correct use of maps we must, however, know the technique of map interpretation.

Map interpretation, like many other aspects of geography, involves a synthesis in which new ideas and facts are built from a set of interrelated details. This point is important to note because many a times map interpretation is considered to be an exercise in describing the individual components as they appear on a map.

By transferring to a sheet of tracing paper any single component of a topographical map, say communication lines, we can see the distribution and direction of the pertinent details. In other words, we can know the things as they are, but we cannot explain them. If we go a step further and transfer two components, say relief and communication lines on the same paper. Such an exercise will not only give the facts relating to the relevant components, but also will provide perceptual basis for understanding the relationships between the two. But even this will fail to give the whole explanation. It will lead to only partial synthesis the whole of which is provided by the original map. The study of individual components of a map separately should be done only as a means to understand the relationships underlying the various components.

A prior knowledge of the physical and cultural geography of the area represented on the map being interpreted, will prove to be a valuable aid to map interpretation.

INTERPRETATION OF TOPOGRAPHICAL SHEETS

The following procedure is suggested for the interpretation of topographical maps:

1. Identify the map and give the marginal data,
2. Interpret the physical data,
3. Interpret the cultural data, and
4. Give the cartographic appreciation.

Identification :

Before starting the interpretation of a topographical sheet, the first thing to do is to identify the sheet and to give the marginal details. On the margins of a map are given the areas to which the map belongs, time of survey, magnetic north, scale, administrative index, contour interval and some other details such as the longitudes and the latitudes.

Physical details :

The following procedure is suggested for the interpretation of physical landscape :

1. Give the broad physical features first. Point out the general lay of the mountains, plateaux and plains. Note also the main rivers, if any and the general slope as indicated by main contours.
2. After noting the broad features, look carefully into the details of each of them. Mention the landforms like peaks, ridges, hills, spurs, escarpments, knolls, cirques, cols, flood plains, valleys, morainic deposits, etc. The number of sectional profiles should be drawn at this stage to indicate the nature of relief. For the method of drawing profiles see chapter XVIII. These profiles will help in the identification of the nature of the landforms mentioned above. For example, they will indicate whether a hill is, residual, moranic or volcanic. Special attention should be paid to the spacing of the contours. Several of the techniques discussed in chapter XVIII can be fruitfully used to identify the landforms.
3. The next stage is to discuss the drainage pattern and the features associated with them. The catchment area of each river or stream should be marked. The glaciers and their morainic deposits should also be marked. A correlation between the contour pattern and the drainage pattern will be very revealing. Longitudinal profiles along a few rivers should be drawn to point out the stage at which different stretches of the streams are. The cross-sectional profiles will give data on the nature of the valleys such as gorge, V shaped, U shaped, broad, narrow, symmetrical, asymmetrical, hanging, transverse, longitudinal etc. The nature of the banks of the rivers and the

formation of flood plains, meanders, oxbow lakes, incised meanders, terraces, swamps, fans, deltaic flats, and tidal deposits, if any, should be noted. The longitudinal profile will give information about the presence of water falls, catracts, rapids etc.

The type of drainage pattern visible in the map should be noted. It will be one or several of the following types:

a) dendritic pattern
b) trellis pattern
c) rectangular pattern
d) radial pattern
e) deranged pattern
f) barbed pattern
g) karst pattern.

Some of these patterns are illustrated in figure 110.

4. Next step is to study the vegetation. The natural vegetation in Indian toposheets is usually shown by green colour. Certain types of trees are shown by symbols.

While interpreting the physical landscape, one has to keep in view W. M. Davis' classification of landscape. According to him, physical landscape is a function of structure, process and stage. It is true that all the three elements cannot be fully interpreted from all the maps. As such no attempt is made here to suggest any steriotype procedure. The procedure will have to vary from area to area and map to map. In certain cases the main interest will have to be focussed on the correspondence between structure and surface relief; in certain others, on the landforms developed in one of the special cycles; while in certain others on the erosional forms belonging to a certain stage of the cycle. While, structure, process and stage must form the basic framework for interpretation of physical landscape, they need not be discussed in that order or with same emphasis.

The problems to be discussed under various headings are given below:

To explain the *process*, the erosion cycle currently in progress should be discussed. It will be one of the following:

1. Normal cycle; 2. Glacial cycle; 3. Arid cycle; 4. Karst cycle.

In case of the normal cycle of erosion, physical evidence of former glacial erosion or deposition and former marine erosion should also be discussed. If there are shorelines in the map, the class, type, and the stage reached in the present shoreline cycle also need to be discussed.

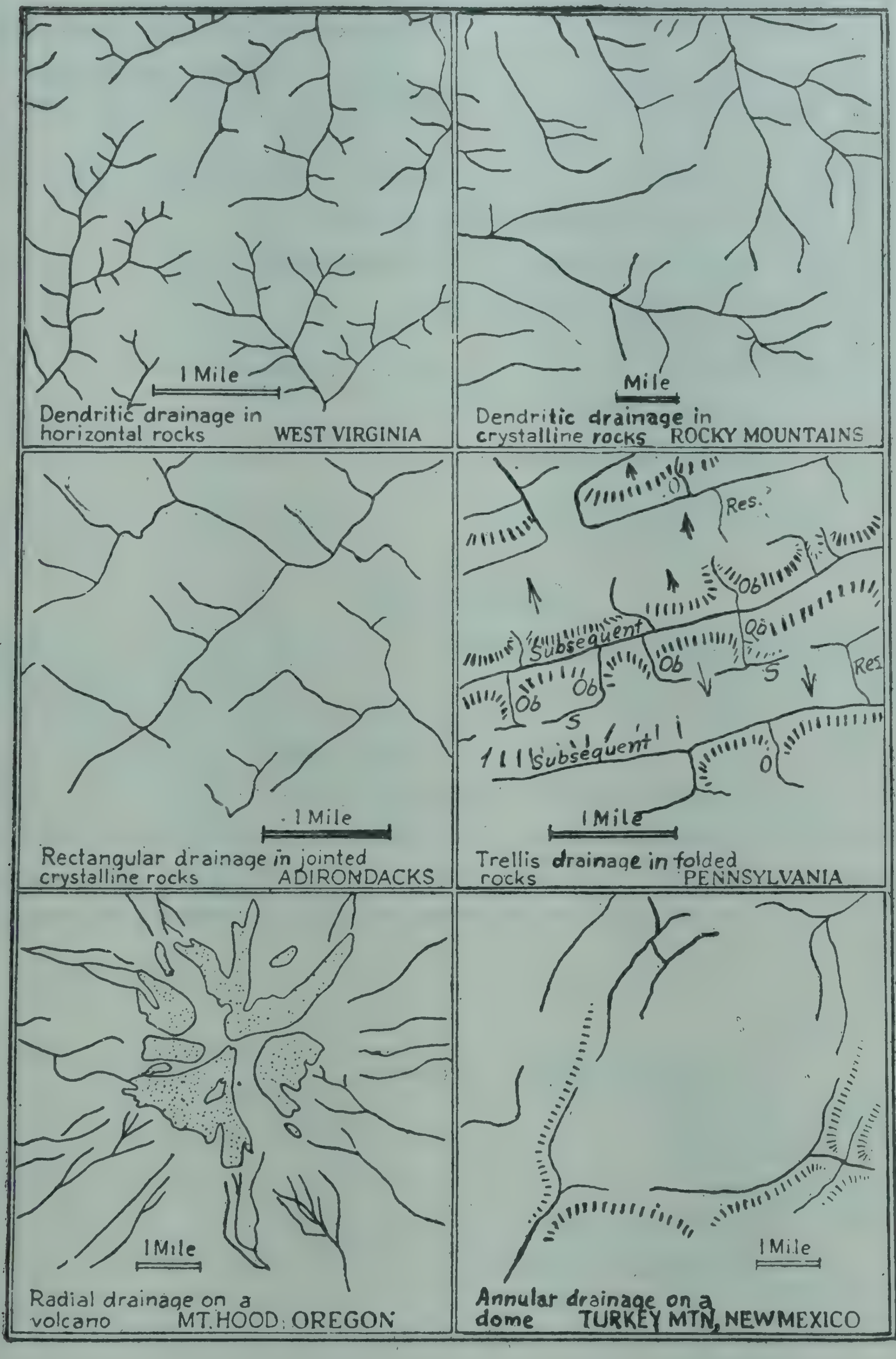


Figure 110 : Drainage patterns

To explain the *Structure* we should discuss the following:

1. Nature of rocks (whether resistant or non-resistant; porous or non-porous, etc.)
2. Types of rocks (Sedimentary, igneous etc., and their sub-types).
3. Nature of beds (faulted, folded etc.)
4. Evidence of volcanic activity, if any.

The *Stage* should include discussion on the following:

1. Stage of landscape development
2. Stage of drainage cycle
3. Relationship between drainage and structure
    a) Well-adjusted
    b) Partially adjusted
    c) Mal-adjusted.
4. Type of drainage pattern.

Cultural Details

It is true that man's activities have not been instrumental in altering the landforms significantly, except locally, they have nevertheless altered certain surface details. The study of cultural features lends itself well to map analysis. It involves the abstraction of a certain data such as roads, settlements, mines etc. from a given composite map on the one hand and the perception of the underlying relationships between the various sets of cultural details as well as between the cultural and physical details, on the other hand.

For the interpretation of cultural details the following outline is suggested:

1. *Landuse:*
    i. cultivated (with types of crops)
    ii. forested
    iii. other uses
    iv. waste
    v. irrigation systems
    vi. land tenure, if given.

2. *Transportation and communication:*
    i. Railways
    ii. Roads
    iii. Cart tracks, Camel tracks, mule paths etc.

iv. Aerodromes
v. Ports and harbours
vi. Telegraph, and telephone lines, post offices. etc.

3. *Settlements :*

i. Rural settlements.
a) units
b) forms
c) size and function
d) density
e) patterns

ii. Urban settlements.
a) site
b) situation
c) form
d) size
e) function.

4. *Other details :*

i. Political boundaries
ii. Archaeological details
iii. Cultural institutions
iv. Occupation
v. Others.

5. *Synthesis :*

Cartographic Appreciation :

Geographic interpretation of a topographical map is not complete unless the interpreter has also expressed his views on the cartographic representation in the map. Cartographic appreciation is the critical assessment of a map. It involves the study of cartographic methods and techniques, and the estimation of their success or failure in the representation of the map details. There are two aspects of cartographic representation which need evaluation ; (1) suitability of symbols used, and (2) the design and aesthetic beauty of the map as a whole. Both of these always form controversial issues because judgements on them is affected by taste, experience and aesthetic susceptibilities of the judges. Cartographic appreciation cannot be learnt by the rule of thumb. Long practice and considerable patience are needed. Comparisons

should be made between maps on different scales but of single surveys, of different series of single surveys, and of different surveys on a single scale before passing a judgment.

A topographical map must omit a great deal of potential material and should achieve some kind of balance in the material actually presented. Many map series achieve praiseworthy success with certain class of information but fail signally in dealing with others. At times an interpreter may also be biased. He may take his own national maps as standard ones and criticize foreign maps having unfamiliar symbols and representation techniques. To give an example, the 1/50,000 maps of Sweden use black hachure formlines instead of contours for representing the relief. One who is used to seeing relief through contours may not like it. But the technique is very suited to the terrain of Sweden. At times a few details are shown too prominently such as waterways in Netherlands. For an arid zone dweller it may appear to be unnatural. But it is not inappropriate in a country where waterways are so important.

It must also be kept in view that the design of maps differs and will continue to differ from country to country. One of the chief reasons for it is that in series mapping wholesale changes are not possible. What is possible in a short run is the creation of a mixture of the old and the new. Although many modern surveys use common techniques, there is no reason to suppose that map styles will so converge as to become identical. So long as the perfect map remains unmade, so long as there is no agreement on cartographic perfection, and so long as improvements in printing processes continue, varying styles in mapping will persist.

While attempting cartographic appreciation, it must be kept in mind that the scale of mapping puts many limitations on the amount and type of information that can be given. The larger the scale, the greater the amount of detail that can be given, at the expense, however, of a larger coverage and also of wider and more synoptic view of the major features of the country side which can be gained from smaller-scale maps.

The balancing of the physical and cultural details marks the success or failure of a map. The cultural patterns must be clear in themselves and clear in their relationship to the underlying terrain if correlations are to be understood and the basic purpose of map interpretation is to be achieved. The success achieved in clear representation of non-landscape features like names, boundaries etc. should also be kept in view. In general the relative importance of these features increases with the scale of the map, for on larger scales there is both more room and greater need for that class of information which is of

use particularly to the indoor map reader. In the assessment of non-landscape features one must first consider how far the information provided suits the scale of the map and the type of terrain. Thus the representation of the least significant non-landscape feature would be justified in a map of a part of sparsely populated Rajasthan but the same details would be quite out of place on a map of densely populated East U.P., though drawn on the same scale.

INTERPRETATION OF GEOLOGICAL MAPS

A geological map suggests the nature of underlying rocks and is extremly useful in determining whether landforms reflect control by lithology and structure or bear more the imprint of geomorphic processes and history.

A geological interpretation of a map should deal with following aspects : (1) succession of beds (2) structure (3) relationship among rock groups (4) topography and its relation to structure, and (5) geological history. In this section certain methods are indicated which can be used in understanding these aspects.

Some of the commonly used terms are defined below to facilitate the interpretation of geological maps.

Geological beds :

These beds occur in the earth's crust resting upon one another as successive layers. The surface of separation between two adjoining beds is known as a " bedding plane ".

Geological outcrop :

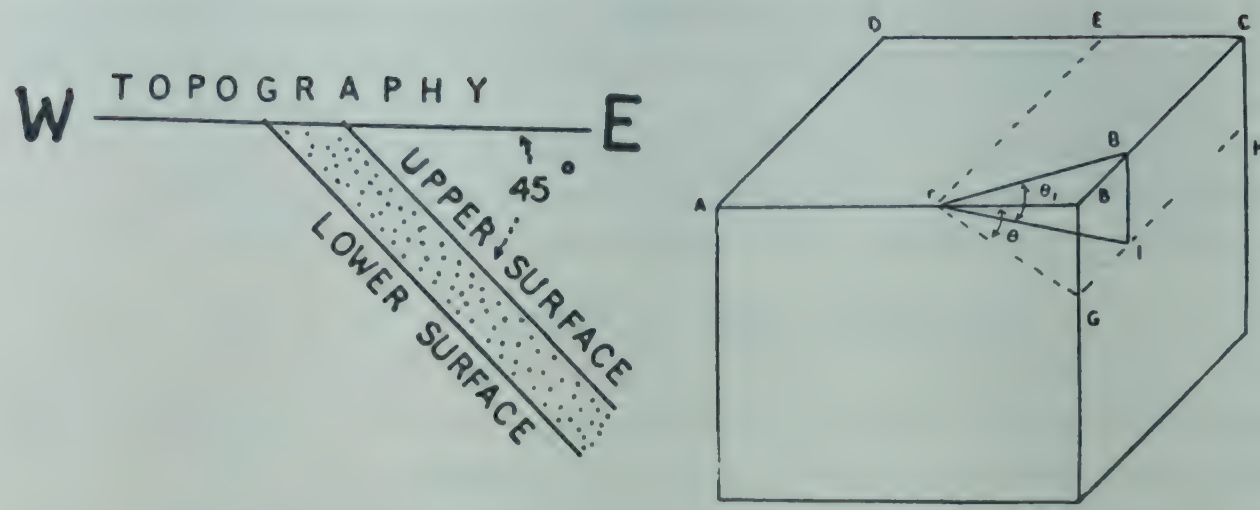
These are the exposed portions of geological beds and formations on the earth surface.

Strike line :

It is a line joining two or more points which lie on the same surface at the same elevation from the mean sea-level. It is also called " structure contour " because it is analogous to the contour lines of the ground surface.

Dip :

Dip of a surface is its inclination with the horizontal plane. The direction of dip is the direction of inclination of a surface. The amount of dip is the angle between inclined surface and the horizontal plane, measured in the direction of the dip (Figure 111a).



(a) (b)

Figure 111 : Determination of (a) true and (b) apparent dip.

True and apparent Dip :

True dip is the amount of dip measured along the direction of maximum slope of an inclined plane. From the fig. 111b it is clear that FB is the direction in which the inclined plane has the minimum slope. ∠ BFG is the true dip.

The apparent dip is measured in any direction other than the direction of maximum slope. Moreover it is always less than the true dip. ∠ BFI is the apparent dip.

Method of drawing strike lines and the determination of dip

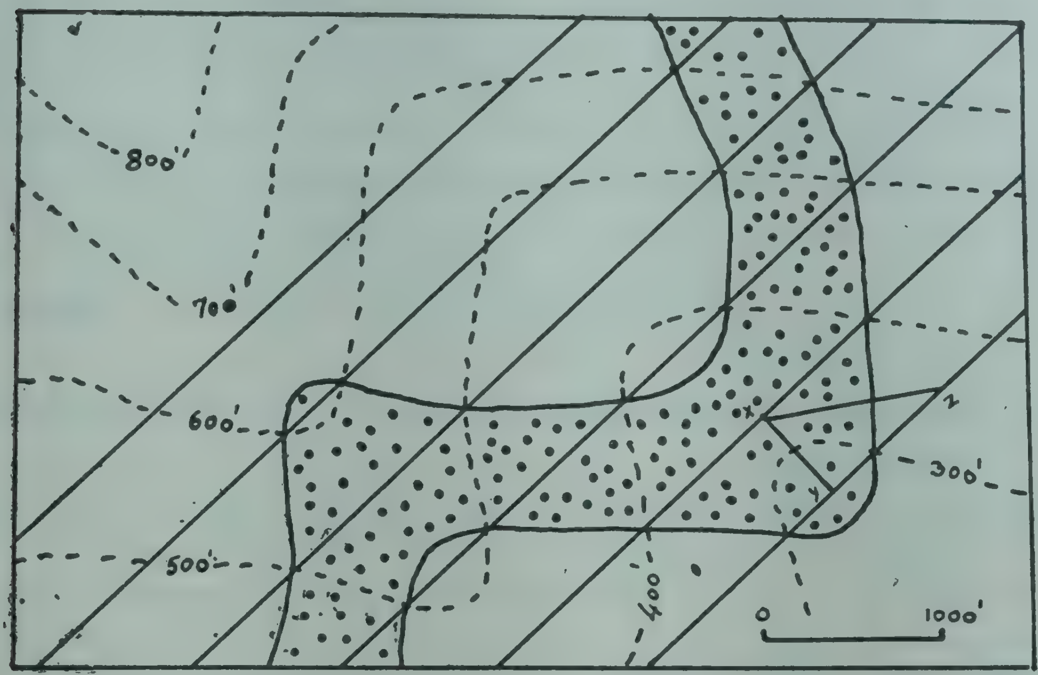
Figure 112a shows the outcrops and the contours. Here the outcrop cuts the same contour at two points. The line joining these two points is the strike line and the value of the strike line is that of the contour line. If another contour is cut by the same outcrop, a strike line can be drawn through the point parallel to the former and the value of the strike line is the value of the second contour. It may be pointed out in this connection that all such strike lines are parallel and equidistant. The direction of dip can be found out by drawing a line at right angles to any strike line towards the strike line of lower value. (as xy in figure 112a)

Amount of dip can be calculated by using the following formula.

$$\text{Dip (in } 0^\circ) = \tan^{-1} \frac{\text{V. I}}{\text{H. E}}$$

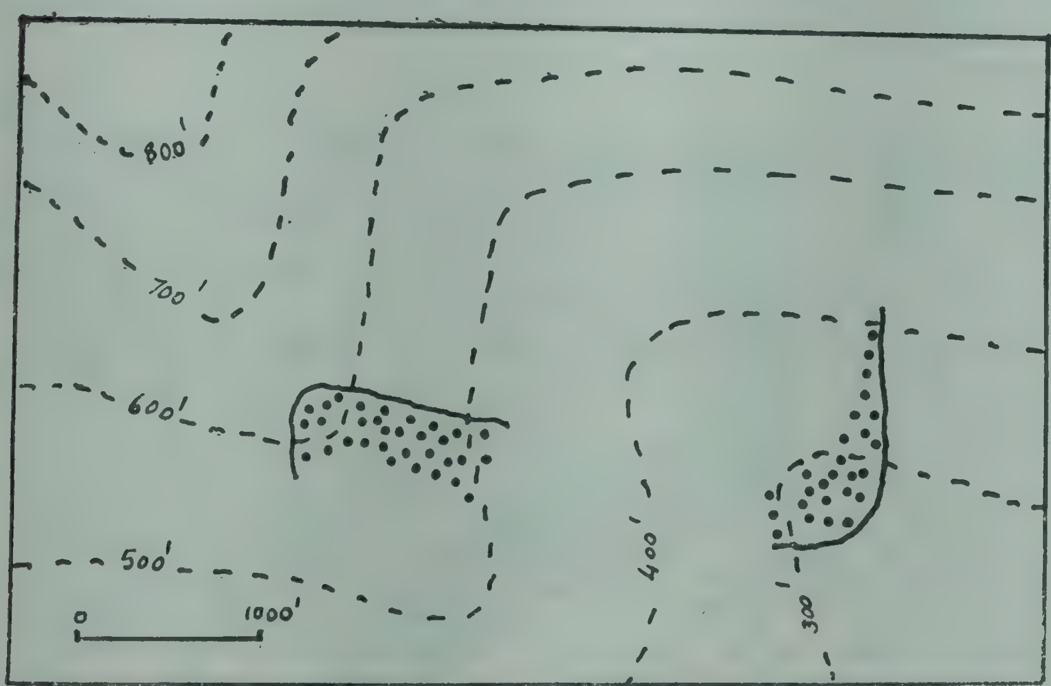
where V. I. = vertical interval of the strike lines

H. E. = horizontal equivalent.



(a)

Figure 112 a : Drawing of strike lines.



(b)

Figure 112b : Completing an outcrop.

Method of completing a given outcrop

Figure 112 b shows the contours and portions of beddings at certain places. At the very outset, a strike line can be drawn, when the same

contour cuts the bed at two places. A second strike line can also be drawn through a point where another contour of a higher or lower value than previous one cuts the same outcrop. This strike line should be drawn parallel to the previous one. With the aid of these two strike lines, other strike lines can easily be drawn. Now, each point where a contour line is cut by a strike line of the same value can be marked. The outcrop can be completed by joining these points by a smooth line. Similarly one can complete a series of outcrops in any map. Following rules may be taken into account while completing an outcrop :

i) The outcrop line can cut only a strike line or a contour where equal values intersect.

ii) An outcrop line must not be taken across any strike lines or any other contour, except at the points of intersection proper.

iii) Outcrop should go right through the point in opposite angle.

Calculation of Bed Thickness :

The vertical distance between the upper and lower surface of the bed is called the vertical thickness of the bed (fig. 113). The true thickness of the bed is the perpendicular distance between the upper and lower surface of that particular bed.

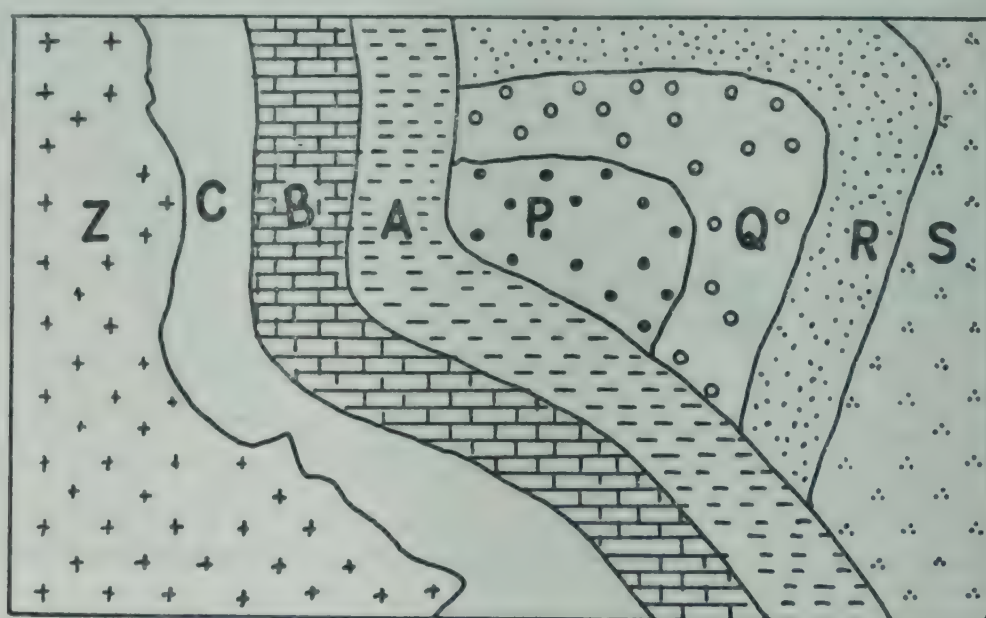


Figure 113 : Determining the thickness of the bed.

From a given geological map, the vertical thickness of a bed can be determined by comparing the strike lines for its upper bedding plane with

those of the lower bedding plane. Suppose the upper value is 600′ and the lower value 400′, the difference i.e. 200′ is the vertical thickness of the bed.

The true thickness can be calculated from the following formula :

$T = t \times \cos$ of the angle of dip.

where $t =$ vertical thickness.

Conformable beds :

A conformable series is one in which the beds are laid down in a period of continuous sedimentation. In other words there is no break or interruption in the deposition of the different beds. Beds which are conformable to one another have the same dip and strike (figure 113). But the dip and strike of the beds of the first series are different from the dip and strike of the beds of the second series.

The relative ages of the beds can be determined from the direction of the dip i. e. "Towards the dip direction a younger bed comes after an older bed." Thus in the given map, under the first series A is oldest, followed by B and C. Similarly, in the second series, P is the oldest followed by Q. R and S.

Unconformity on a geological map :

It is a break in a stratigraphic sequence and represents an interval in sedimentation and a period of erosion of the older rocks. It is usually indicated by a wavy line in geological sections. Unconformity on a geological map can be indentified by observing the following characteristics :

a) Variations of structure — Two series of beds will have different attitudes and structures.
b) Truncation of outcrop—Against the line of unconformity the outcrops of the beds of the old series are abruptly ended or truncated.
c) Trijunction points—Three beds may meet at a point on a line of angular unconformity. By finding such points, the line of unconformity can be traced on the map.

Method of studying folds and faults :

Folds : In figure 114a the map shows series beds viz. U. Q, S. T. R. W, P and a dyke denoted by V. It is obvious from the map, that there are three structural features. viz. (a) unconformity, (b) Fold, and non-unconformity, and (c) intrusive contact. Now, the fold can be identified on the map by means of following factors.

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i) *Repition of outcrops:*

This is mainly due to the erosion of the upper part of the fold. The beds of the series A are folded. One can easily observe the repetition of the outcrops of S, Q, U and T and the reversal of dips of the beds. It is also clear from the map that in the central part of the area, the beds T, S and Q on both sides of the bed R are dipping away from the bed Q. Here, the core of an antiform is R, and T, S and Q are the limbs. Similarly, in the western part of the area U is the core of a synform. Suppose the succession is normal, then we can group the beds of A, B, C in the following order.

P	Formation (B)	
W		
————	————	unconformity
V	Formation (C)	
————	————	intrusive contact
U		
Q		
S	Formation (A)	
T		
R		

ii) *Reversal and variation of dip:*

The following criteria help us in indentifying the type of fold:

a) Anticline—the two limbs dip away from the axial plane.

b) Syncline—the two limbs dip towards the axial plane.

c) Plunging fold—the axis is not horizontal but dipping.

Fault: It is a dislocation along a plane of fracture in rock strata. The plane of dislocation is called fault plane. Before dealing with the geological maps, it is necessary to know the characteristics of a fault.

Slip: This is measured on the fault plane. Slip is the relative displacement of points on opposite sides of the fault which were formerly in contact with each other before faulting.

Pitch: It is the angle between a line on an inclined plane and the horizontal line (strike) on that plane.

Hade: It is the angle measured between the vertical plane that strikes parallel to the fault plane.

Throw: Throw can be measured on a vertical section perpendicular to the strike of the fault plane.

Heave: The horizontal component of dip separation between the up throw and the down throw side is known as heave.

A fault can be recognised on a geological map with the aid of the following criteria.

a) Presence of a fault line

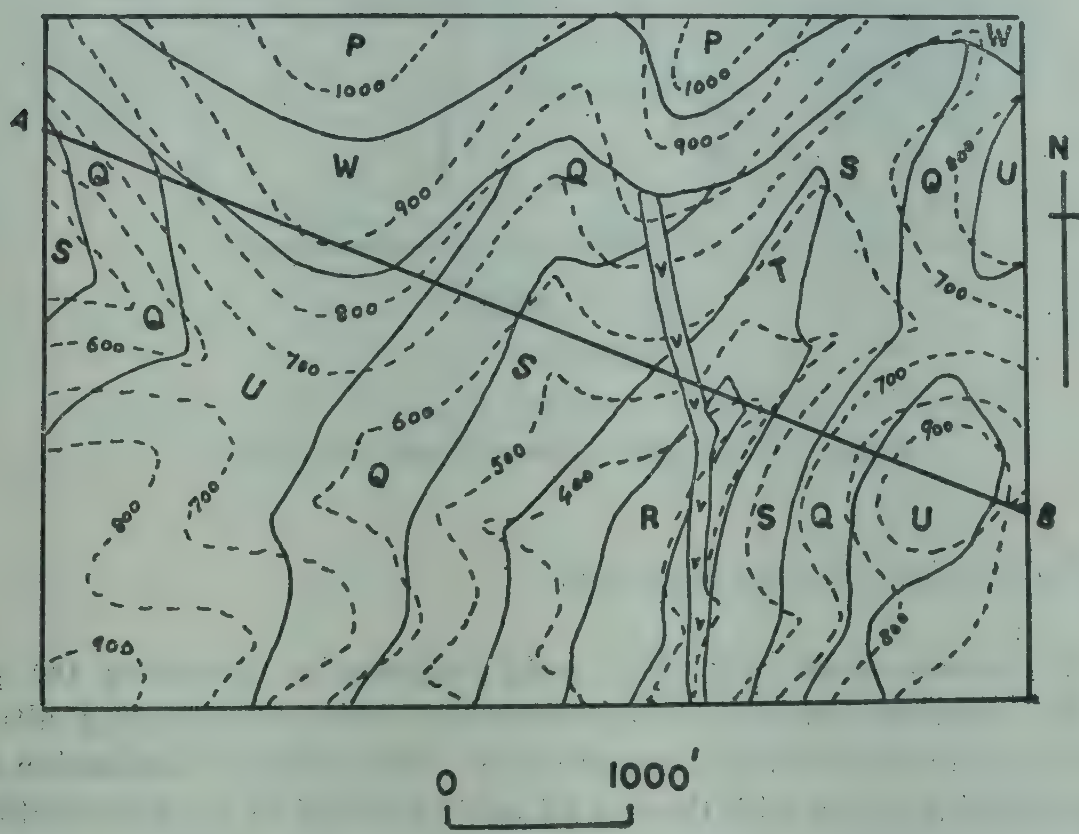
b) Discontinuity of the outcrops

c) Change in the strike on the opposite sides of the fault line

d) Repetition or omission of strata.

Method for determining the throw:

Figure 114b shows a fault F F. Here the conformable beds are affected by fault dip towards the south-east. Two strike lines a_1 b_1 and a_2 b_2 can be drawn for the upper surface of the bed P corresponding to 400 ft and 500 ft.

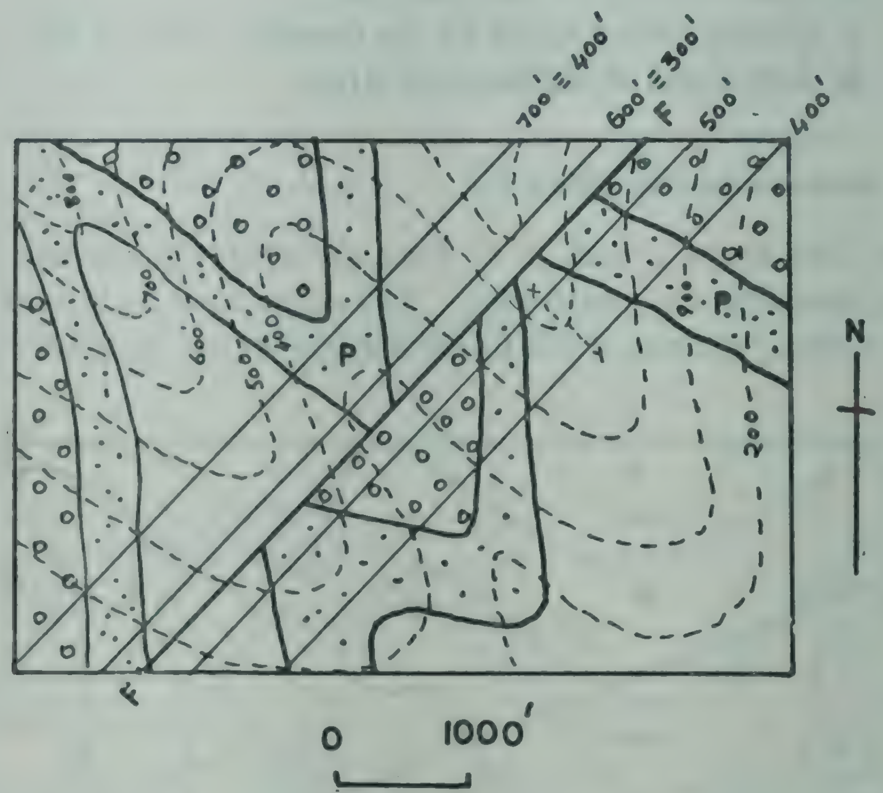


(a)

Figure 114 a : Identification of folds and faults.

Then the distance xy viz. 400–500 ft. strike line should be measured. Now the 600 ft. strike line passes through a_3, the intersection point of the upper surface of the bed P and 300 ft. contour. This strike line is drawn in the direction opposite to the dip of 500 ft. strike line and at a perpendicular distance equal to xy. Now, this strike line of the upper surface of the bed P actually

becomes the 300 ft. strike line. Hence the throw is 300 ft (600′–300′ = 300′) down in the north-western part of the fault. Thus it is obvious that the south-eastern part is the up-throw side.



(b)

Figure 114 b : Identification of folds and faults.

Method of drawing a geological section :

At the very outset the profile should be drawn by projecting the points where the contours cut the lines of section to their corresponding altitudes. These points can be joined by a smooth line. The points of intersection of the different bedding planes with the line of section should be marked carefully on a piece of paper. Then, these points are projected on the profile with the aid of the base of the section.

The apparent dip of the beds can be utilised to draw angles on the base in the direction to which they are dipping. Again, these points can be projected on the profile and the parallel lines drawn. One need not use the same scale for horizonal and vertical axes because the section should be a natural one.

Some of the rock symbols used in geological mapping are given in figure 115.

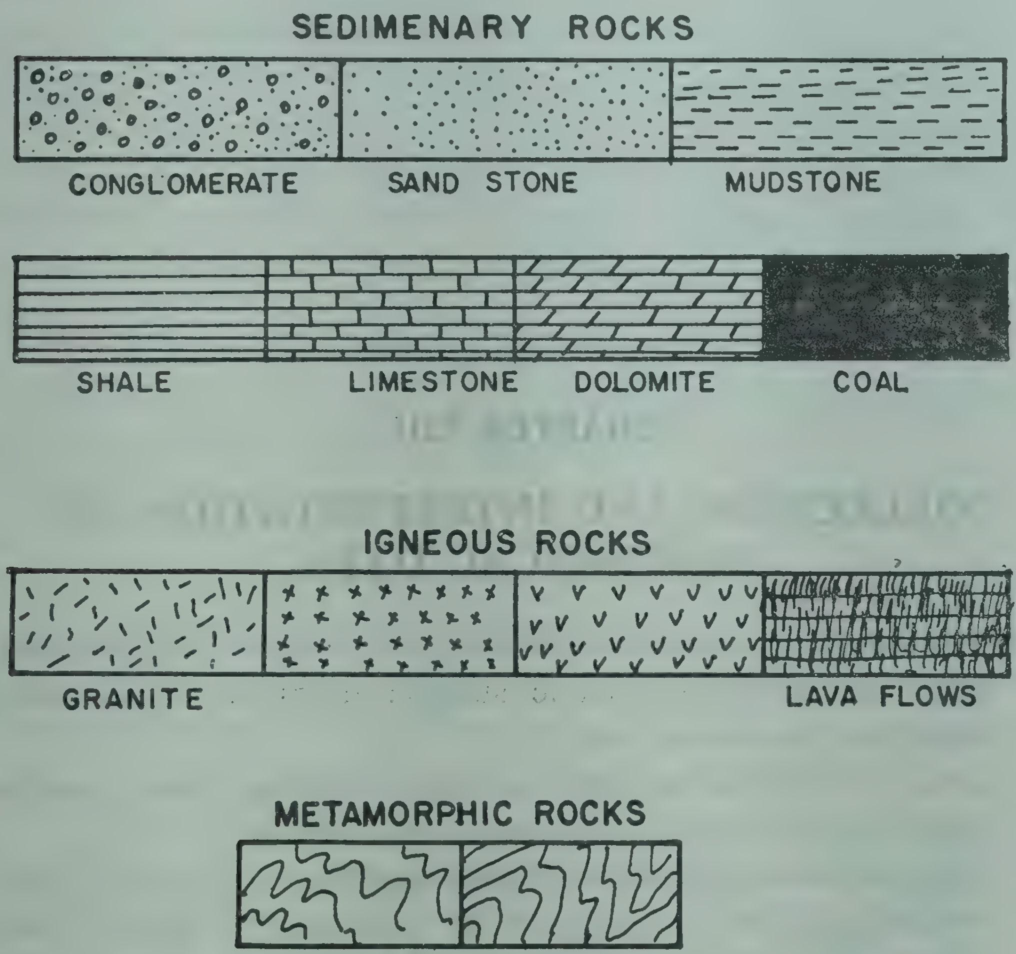


Figure 115 : Some of the rock symbols used in geological mapping.

CHAPTER XIII

COLLECTION AND INTERPRETATION OF STATISTICAL DATA

The data used in various cartographic products are of the following types :

1. Data derived from geodetic surveys giving latitudes, longitudes, directions, elevations, etc. ;
2. Data derived from geodetic and plane surveys giving locations and distribution of various topographical features ;
3. Qualitative and quantitative data supplied by various public and private agencies (or gathered by individuals) showing the spatial arrangement of such tangible and physically existing facts like population, agriculture, industry etc, etc.
4. Qualitative and quantitative data derived from the analysis of facts supplied by various public and private agencies but which do not exist on the ground such as choropleth lines showing the distribution of various phenomena, statistical maps showing deviations, correlations, etc.
5. Qualitative and quantitative data which may be imaginary are used to show patterns and distributions which may come into existence in future.

The geodetic and plane surveys offer only first and second type of data. For the rest, we have either to conduct socio-geographic surveys or to depend upon reports, statistical handbooks and other publications issued by various international, national, regional, and local agencies.

SOCIO-GEOGRAPHIC SURVEY

METHODS

There are two basic methods of socio-geographic survey. These are (1) census method and (2) sampling method. The census method is one in

which each unit of the ' population ' or ' universe ' is taken into account. In the suruey of population on national scale, almost all the countries of the world use census method. In this system each individual is located and counted. In the case of sample studies, however, each unit is not taken into account. Instead, only limited units are studied, and it is presumed that the characteristics of this representative number are also the characteristics of the whole universe. The selection of samples is based on certain rationale and therefore is not arbitrary.

RELATIVE ADVANTAGES

Which of the two methods should be used in socio-geographic survey, depends upon a variety of factors. These are:

Accuracy :

Census method is more reliable than the sampling method. No matter how good is the selection of samples, there is always the likelihood of discrepancy. But the census method, being too laborious, also suffers from errors brought in by double-counting etc.

Purpose :

The method to be used will depend upon the purpose for which the survey is being undertaken. If the purpose is to know the number of units a small area has, we should use the census method. But if the objective is to know about a fairly large area, sample method will be more appropriate.

Time :

If data are to be gathered in a short time, one will have to adopt sample method, provided, of course, that other things are favourable. Census method is time consuming.

Cost :

Census method is a very costly affair. If the resources available are limited, it is desirable to use the sample method.

Area :

Sampling method is less suited to areas where the universe is marked by irregularities.

SAMPLING TECHNIQUES

Sampling is the technique of selecting a set or represntative units from a universe. The chief problem in sampling is how to make the sample a true

representative of the universe. This brings us to the questions of how many and which of the samples should be selected. One may suggest that a number of typical units may be selected as samples. This, however, raises the controversy as to what constitutes a 'typical unit.' The unit that is typical for one person may not be typical for others. If a biased selection is made the samples cannot represent the whole universe.

To make the samples representative of the universe they must be chosen at random. In this method each unit has an equal chance of being included in the sample. This can be achieved in following ways: (1) By arranging the units of the universe in an ascending or descending order and selecting every fifth or tenth, or hundredth unit, as the case may be. The order may be based on quantitative values or alphabets, depending upon the nature of the universe. (2) By using a random number table. Thus, if the data consists of 100 items listed in order of magnitude or in some other order, we can select from the table of random numbers, the number of samples we want to select. One can get a table of random numbers in any elementary book of statistics.

If the universe is not uniform and there are areal or other differences in it, stratified sampling needs to be used. In this type of sampling, samples are selected from each stratum of the universe. In geographic analysis we often have to study areal differences. It is some times called area sampling. It is a form of stratified random sampling.

There are several other types of sampling devices which are not discussed here.

Unless the data needed are very limited, one has to prepare a schedule or a questionaire for their collection. Schedules are usually in the form of proforma, the filling of which gives the needed information. A schedule or a questionaire can be filled by the enumerator himself or he may get replies by mail. The method used will depend upon the time and resources at the disposal of the investigator.

LIBRARY RESEARCH

Library research involves the collection of mappable data from various published or unpublished sources. The secondary sources contain a variety of data from which a cartographer has to cull out those which are useful for his purpose. Before using such data, he must, however, make sure of their reliability. He must find out the agency which collected the data and the method it used in doing so. If the methods used were not rational, the data cannot be reliable.

If several sources are used, it is often found that the data are not comparable. There are many reasons for the lack of comparability among

which (1) changes from fiscal to calender year or vice versa and (2) revision of data and change in the definition of the terms used, are important. For example, in certain years, the urban areas may be treated as those which fall within municipal boundaries but later they may also constitute areas with certain density of urban population. It is very important that the map maker is aware of the limitations of the data before using them so that he can devise ways and means to deal with them in the construction of his map.

The secondary data used for mapping can be divided into two types; (1) published and unpublished records, and (2) published and unpublished maps. It will, indeed, be difficult to list all such sources in a single chapter.

The United Nations and its specialized agencies, trade associations, trade, financial, industrial and professional journals, government and private statistical organizations, universities and colleges involved in research are the important sources of statistical data. A cartographer should have the knowledge of the organizations which can supply the needed information. For example, he must know that the Census Bureau in the U. S. A. and Census of India office in India are responsible for collecting population data for their respective countries.

In addition to the published and unpublished data available from various organizations and reports, one can get cartographic data from a variety of publications. A number of encyclopedia are there in the libraries which can assist a cartographer in getting desired information. Several professional journals give maps as well as details of various countries and regions.

Another important source of information is the published maps. In order to make the best use of this source of information, it is desirable to know the organizations which publish various types of maps. Some of these organizations are discussed in chapter XI.

INTERPRETATION OF STATISTICAL DATA

Data collected from both primary and secondary sources are of two types: (1) qualitative, and (2) quantitative. An attempt is made here to give in a summary form the methods of interpretting the quantitative data.

FREQUENCY DISTRIBUTION

The first step in the interpretation and use of statistical data is their summarisation. One method of summarising is the preparation of frequency distribution. Frequency distribution arranges the items of a series into groups or classes and indicates the number of cases occurring in each group.

Suppose we are given the rainfall data for 21 years (Table 8), We can prepare a frequency table as given in table 9.

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Table 8: *Rainfall of a town: 1947–1967.*

Years	Rainfall in inches	Years	Rainfall in inches
1947	20	1958	8
1948	36	1959	11
1949	37	1960	26
1950	15	1961	14
1951	10	1962	17
1952	5	1963	20
1953	25	1964	18
1954	23	1965	13
1955	18	1966	12
1956	35	1967	28
1957	19		

Table 9: *Frequency of rainfall occurrence*

Rainfall in inches	*Frequency of occurrence*
1–10	3
11–20	11
21–30	4
31–40	3

After the data are classified the frequencies are plotted against appropriate classes and diagrams in the form of building blocks or linegraphs are drawn. The examples of such diagrams are given in chapter XX.

AVERAGES

We have seen how individual sets of data vary among themselves. In order to make the variable data useful for cartographic representation, we have to know the amount of variation. This will make the various sets of data comparable. Before we can know the amount of variation, we have to know the base for measuring the variations. Mean or average provides one such base.

Averages are the generalized values representing a series. This value is chosen so as to give as reasonable an approximation as possible to what is normal.

There are 4 main types of averages. These are (1) arithmetic mean, (2) median, (3) mode, and (4) geometric mean. To understand the differences between them, we will have recourse to the following example.

Suppose we have the following set of data : 1, 2, 2, 3, 3, 3, 3, 4, 4, 5.

In this case the total of these values is 30. If this is divided by the number of items involved i.e. 10, the answer is 3. This three is the arithmetic mean of the data. Now if we arrange the data in order of magnitude as it is presented above and find the mid-value we get 3. The mid-value of a set of data is called the median. Supposing we take into account the frequency of each value in the data and select the one which occurs most often, we get an average which is called the mode. In this particular case we see that 3

Value	*Frequency*
1	1
2	2
3	4
4	2
5	1

occurs four times. These methods give a value which to some extent represents the series. We will now go into a little greater detail.

Arithmetic Mean:

The above example of the mean can be expressed in following shorthand form:

$$\overline{X} = \frac{\Sigma X}{N}$$

where X = the individual values making up the Series of data;

$\overline{X}$ = the arithmetic mean

N = frequencies

Σ = (Sigma) the summation or total of all the values of $\overline{X}$.

So long as the data are given in the form given above we can use the above formula, but if they are given in a grouped form, the formula becomes complicated. We cannot go into the details of the derivation of the formula. The reader is referred to a beginning book on statistics. Here, only the formula and its application are given.

Formula for the grouped data:

$$\overline{X} = \frac{\Sigma f X}{N}$$

Now let us work out the arithmetic mean for the data given in Table 10.

Table 10: *Sales checks in a store*

Class	Mid point X	Class frequency f	frequency multiplied by mid-point, f X.
Rs. 1 and under Rs. 3	Rs. 2	3	Rs. 6
Rs. 3 and under Rs. 5	Rs. 4	9	Rs. 36
Rs. 5 and under Rs. 7	Rs. 6	25	Rs. 150
Rs. 7 and under Rs. 9	Rs. 8	35	Rs. 280
Rs. 9 and under Rs. 11	Rs. 10	17	Rs. 170
Ri. 11 and under Rs. 13	Rs. 12	10	Rs. 120
Rs. 13 and under Rs. 15	Rs. 14	1	Rs. 14
		100	Rs. 776

$N = 100 \qquad \Sigma f X = \text{Rs. } 776$

$$\therefore \overline{X} = \frac{\Sigma f X}{N} = \frac{\text{Rs. } 776}{100} = \text{Rs. } 7.76$$

Thus the mean sale for the store is Rs. 7.76

Median :

As indicated earlier median is that value of the variate which lies midway when the data are arranged in order of magnitude. Median value can be found out by the median observation which in turn is the $\frac{n+1}{2}$ th observation. If there are 9 observations, then median observation will be $\frac{9+1}{2} = 5$th. If there are 10 observations, then the median will fall somewhere in between observations no. 5 and 6. If the values of the two observations are 4 and 6, then the median is $\frac{4+6}{2} = 5$.

In the case of grouped data, the following formula should be used :

$$\text{Median} = L_1 + \left(\frac{\frac{N}{2} - \Sigma f_1}{fm}\right). X$$

where L_1 = lower limit of the median class.

N = Total frequency

Σf_1 = the sum of all frequencies accumulated before entering the median class.

fm = the frequencies in the median class.

X = the size of the class interval of the median class.

The procedure for finding the median for grouped data is given in Table 11 :

Table 11 : *Finding the median for the size of industrial establishments by number of workers.*

No. of workers.	No. of establishments (= frequencies)	cumulative frequency.
0 to 49	46	46
50 to 99	59	105
100 to 149	45	150
150 to 199	37	187
200 to 299	31	218
300 to 399	20	238
400 to 499	13	251
500 and over	9	260

$N = 260$;

$\frac{N}{2} = 130$

$L_1 = 100$

$\Sigma f_1 = 105$

$fm = 45$

$X = 50$

$$\therefore \text{Median} = 100 + \left(\frac{130-150}{45}\right) 50$$

$= 127.78$ workers or 127.8 workers.

As apparent from the above example, a median divides the data into two equal parts. It is therefore, called Q_2 which means second quartile. Quartiles marking the limits of lower and upper quarters, are known as 1st and 3rd quartiles respectively. Similarly, particular values which divide the total observations into 10 and 100 equal parts, are respectively known as deciles and percentiles. The quartiles are denoted by Q_1, Q_2, Q_3, whereas deciles and percentiles by $D_1, D_2 \ldots D_n$ and $P_1, P_2 \ldots P_n$ etc.

The quartile observations are ascertained by the formula :

$$Q_1 = \frac{n+1}{4} \text{th observation}$$

$$Q_2 = \frac{n+1}{2} \text{th observation}$$

$$Q_3 = \frac{3(n+1)}{4}\text{th observation}$$

If the series is a discrete one, the values can be computed by the formula :

$$Q = L_1 + \frac{(L_2 + L_1)}{F} \quad (q-c)$$

where L_2 and L_1 are upper and lower limits of the quartile class.

F = frequency of the quartile class.

q = quartile observation.

c = cumulative frequency previous to quartile class.

Similar methods can be adopted in the calculation of deciles and percentiles.

$$D_1 = \frac{n+1}{10}\text{th observation}$$

$$D_9 = \frac{9(n+1)}{10}\text{th observation}$$

$$D = L_1 + \frac{L_2 - L_1}{F} \ (d-c)$$

$$P_1 = \frac{(n+1)}{100}\text{th observation}$$

$$P_{50} = \frac{50\,(n+1)}{100}\text{th observation}$$

$$P = L_1 + \frac{L_2 - L_1}{F} \ (p-c)$$

The above derivations prove that Median = $Q_2 = D_5 = P_{50}$

Mode :

We have seen that mode is the value which occurs most often in a distribution. In a grouped data the class having the maximum frequency is known as the modal class.

The formula for the grouped data is

$$\text{Mode} = L_1 + \frac{\Delta_1}{\Delta_1 + \Delta_2}.X$$

where L_1 = the lower limit of the modal class.

Δ_1 = difference between the frequencies in the modal class and pre-modal class.

Δ_2 = the difference between the frequencies in the modal class and post-modal class

X = the size of the class interval of the modal class.

To find the mode we may take the example given in Table 12.

Table 12: *Weekly income of workers in a factory*

Weekly income (in Rs)	No. of workers.
10 and under 20	85
20 and under 30	120
30 and under 40	110
40 and under 50	67
50 and under 60	49
60 and under 70	21
70 and under 80	6
	458

Here $L_1 = 20$; $\Delta_1 = 35$; $\Delta_2 = 10$; $X = 10$

(Note: the modal class is the class with largest frequencies, and here it is 120)

$$\text{Mode} = 20 + \left(\frac{35}{35+10}\right) 10$$

$$= 20 + 7.78 = \text{Rs. } 27.78$$

Geometric Mean:

The geometric mean is a type of mean chiefly useful in averaging ratios, and in computing average rates of increase or decrease. In other words it is the Nth root of the product of N items. If there are two items, we take the square root; if three, the cube root, and so on. If there are zeros or negative values in the series the geometric mean can not be used.

The formula is G = nth product of the X's

Relationship between the means:

The average, the median and the mode are the main methods of expressing the mean values of a set of data. It would, therefore, seem desirable to consider briefly the relationship between them and to try to see which one to use where and why. Let us take the first example of the series. 1, 2, 2, 3, 3, 3, 4, 4, 5, where mean, median and mode coincide. If this series is plotted on a histogram, it would appear as in figure 116. The distribution that we see in the histogram is called normal distribution. And the curve we get, is called a normal distribution curve. The existence of normal distribution is assumed in most statistical analysis, although in practice, it is seldom perfectly achieved. If this series is changed to:

1, 1, 2, 2, 2, 3, 3, 4, 4, 5

We get average $= \overline{X} = \dfrac{\Sigma X}{N} = \dfrac{27}{10} = 2.7$

Median $= 2.5$

Mode $= 2$

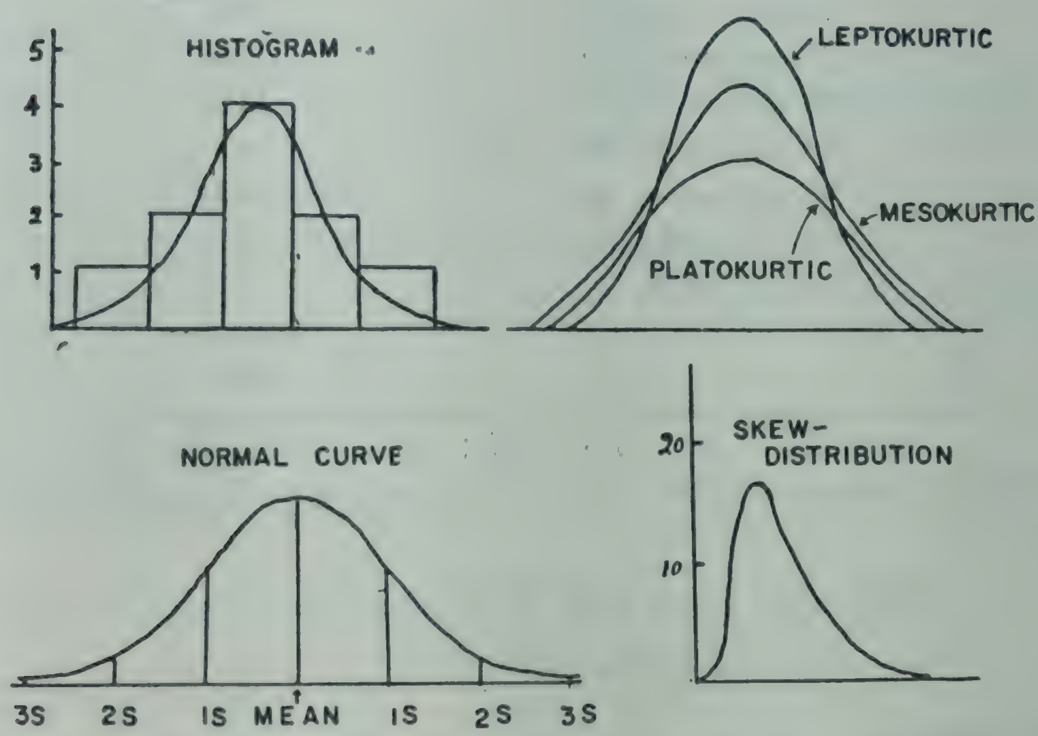

Figure 116 : Histogram and various types of curves

This distribution is not normal. It is a skewed distribution. If the tail extends to the right as in this case, it is called positive skewness, and if to the left, then negative skewness.

Advantages and disadvantages :

The mode, by its very definition, indicates what is most common or frequent. Very often, however, there is some difficulty in deciding exactly where the mode occurs. This may be either because the data are bi-or multimodal or the selection of the classes is biased. Median represents the mean expectation in that there are as many individual occurrences above it as there are below it. In the calculation of the median every occurrence is given the same weight, i.e. it is regarded as of equal importance no matter of what magnitude it is. This means that widely differing sets of data can return the same median value. Further this implies that the median possesses no real mathematical qualities and cannot be used for further computations. In this way it suffers from the same limitation as does the mode.

Among the three types of averages it is only the arithmetic mean which is based on sound mathematics and which, therefore, possesses properties which

permit its use in mathematical manipulation of the data. It is, nevertheless, essential that the implications and limitations of the mean should also be appreciated. In the calculation of the mean weight is given to each occurrence according to its magnitude. So that if the output of one farm is Rs. 2000 and that of the other is nil, the average comes to Rs. 1000/–. This naturally does not give a realistic picture. For a proper appreciation of the significance and relevance of any mean value it is also necessary to know something more of the distribution which the mean summarizes. It is desirable to know how actual conditions are scattered around the mean value.

DEVIATION OR VARIABILITY

Deviation or variability means the distances at which the variates stand from the mean. Generally there are two types of deviations. They are :

1. Absolute, and 2. Relative

Positional Measures:

There are two positional measures of absolute variation, viz. (1) Range, and (2) Inter-quartile deviation.

Range : If we indicate the lowest and the highest values along with the mean then we give the range of deviation. For example the following two sets of data have the same averages but different ranges. In the first case the range is 1 to 9 while in the second 3 to 7.

set I. 1, 3, 5, 7, 9. average = 5
set II. 3, 4, 5, 6, 7. average = 5

But this gives insufficient information for most purposes.

Inter-quartile deviation : This is another form of scatter which is used in conjunction with the median.

$$\text{I. Q. D.} = \frac{Q_1 - Q_2}{2}$$

where Q_1 and Q_2 are the upper and lower quartiles respectively.

Average (mean) deviation and the standard deviation are the two most commonly used methods to find out absolute deviation. Both take into account the deviation of each item in a series from an average.

Average deviation:

It tells us by how much each occurrence differs from the average. These differences are then added together. The added sum is then divided by the number of items (Table 13)

Table 13

Items	Values (X)	Deviations (D)
1	1	— 4
2	3	— 2
3	5	0
4	7	+ 2
5	9	+ 4
5	25	12

$\overline{X}$ (Mean) = 5 ; Σ D = 12 (+ and — Signs ignored).

$$\text{Average deviation} = \Sigma \frac{D}{\overline{X}} = \frac{12}{5} = 2.4$$

In this case 2.4 is the mean deviation. It may be noted here that in the calculation of this no consideration has been given to positive and negative deviations.

Standard deviation :

We have noted already that we ignore the + and — signs in the calculation of mean deviation. One way of avoiding this mathematically irrational method is to square all the deviations. This is what we do when we derive standard deviation. (Table 14)

Table 14

X	D	D^2
1	–4	16
3	–2	4
5	0	0
7	+2	4
9	+4	16
$\overline{X} = 5$		$D^2 = 40$

Now $\Sigma D^2 = 40$

$$\therefore \text{ the variance} = \frac{\Sigma D^2}{N} = \frac{40}{5} = 8$$

The value derived from dividing the squared deviations by the number of values, is called the variance. Here 8 is the variance. If we calculate the square root of the variance, we get a value which is called the ***Standard deviation.***

The shorthand formula for the two are given below :

$$\text{variance}\ (\sigma^2) = \frac{\Sigma(X - \overline{X})^2}{n}$$

$$\text{Standard Deviation}\ (\text{S.D. or } \sigma) = \sqrt{\frac{\Sigma(X - \overline{X})^2}{n}}$$

In the above measurements we have used the absolute values. Dispersion can also be shown relatively by using the indices of variability. The following are the main indices.

Index of variability :

$$\frac{\text{Quartile deviation}}{\text{Median}} \times 100\ \%$$

Co-efficient of variation :

$$\frac{\text{Standard deviation}}{\text{Mean}} \times 100\ \%$$

Relative variability :

$$\frac{\text{Mean deviation}}{\overline{X}} \times 100\ \%$$

Pluvio-metric co-efficient :

$$cp = \frac{r}{R\,\frac{m}{365}}$$

cp = pluviometric co-efficient
r = rainfall in month
R = annual rainfall
m = number of days in that month

NORMAL CURVE AND PROBABILITY

In the previous section it has been shown that in order to represent a body of data adequately two parameters (characteristics) need to be defined ; (1) the mean and (2) the deviation. It has also been said that the arithmetic mean and standard deviation are the best methods of doing so.

However, if we were to state that the yield of wheat per acre for a series of farms was 30 bushels and that the standard deviation was 5 bushels, what would it imply ? If the data were symmetrically distributed about the central point which is arithmetic mean we will get a normal curve (figure 116.)

In the above figure the average $\overline{X}$ is 30 and standard deviation 5. We see that one standard deviation away from $\overline{X}$ i.e. 30 ± 5 lie, 68 percent of the occurrences and at 2 standard deviation away lie 95% of the occurrences and so on. To be rather more precise, these values imply the following provided that the curve is perfectly normal:

68.3% of the occurrences will lie between $\pm 1\ \sigma$
95.45% of the occurrences will lie between $\pm 2\ \sigma$
99.7% of the occurrences will lie between $\pm 3\ \sigma$
99.99% of the occurrences will lie between $\pm 4\ \sigma$

But all the data that we come across are not normally distributed. More often than not, they are assymmetrically distributed. In the symmetrical distribution the three measures i.e. mean, median and mode are coincident but in an assymmetrical distribution they are different. The measure of assymmetry is called skewness.

Skewness is of two types: (1) positive (2) negative. A curve has positive skewness if the mean exceeds the mode; and negative skewness if the mode exceeds the mean.

Skewness can be measured by co-efficient of skewness:

$$\text{Skp} = \frac{3\,(\overline{X} - \text{median})}{\text{S D}}$$

where Skp = Co-efficient of skewness
$\overline{X}$ = mean
S D = Standard deviation.

Greater the value more the skewness.

But even when the distribution is symmetrical, the shapes of the curves may differ. In other words, all symmetrical curves are not normal. The departure of a symmetrical curve from the normal is called kurtosis. If the curve is too tapering, the curve is called lipto-kurtic, when too flat it is called platikurtic, but when it occupies a middle position, we call it meso-kurtic (Figure 116).

CORRELATION

So far, we have seen the characteristics of a given set of data pertaining to one variate. In many problems, however, there is the need to compare sets of data in terms of the extent to which a change in one is or is not reflected by a change in the other. This necessarily implies that the individual items of the two sets of data coexist either in time or space such that the possibility of interrelated changes can be considered. In such a problem an index is required that reflects the degree to which changes in the direction (+ or —) and

magnitude in one set of data are associated with comparable changes in the other set.

Coefficient of correlation:

One of the indices which measures association is called product moment correlation. The coefficient of correlation varies from -1 to $+1$. If it is -1 or nearer that it means that the variables have negative relation with each other i.e. when one increases the other decreases. But if it is $+1$ or nearer that it means they have perfect or high positive relationship. If it is 0, it means no relationship.

Let us take one specific example. Table 15 gives the employment figure as well as the sales in rupees.

Table 15. *Employment and sales in a store.*[7]

Employment (in thousands of workers) X	Annual sales (thousands of Rupees) Y
22	250
31	200
90	980
82	850
43	710
65	280
59	630
16	180
61	670
46	420
35	190
50	460

The basic formula for the derivation of coefficient of correlation is

$$r = \frac{\Sigma \frac{x}{SDx} \cdot \frac{y}{SDy}}{N} \quad \text{or} \quad \frac{\Sigma xy}{\sqrt{\Sigma x^2 . \quad y^2}}$$

where SDx and SDy = Standard deviations.

N = Number of items

x and y = Deviation values of X and Y respectively.

Table 16. *Computation of the coefficient of correlation from the data given in table 15.*

X	Y	$x = X - \overline{X}$	$y = Y - \overline{Y}$	xy	x^2	y^2
22	250	—28	—235	+ 6,580	784	55,225
31	200	—19	—285	+ 5,415	301	81,225
90	980	+40	+495	+19,800	1600	245,025
82	850	+32	+365	+11,680	1024	133,225
43	710	— 7	+225	— 1,575	49	50,625
65	283	+ 15	—205	— 3,075	225	42,025
59	630	+ 9	+145	+ 1,305	81	21,025
16	180	—34	—305	+10,370	1156	93,025
61	670	+11	+185	+ 2,035	121	34,225
46	420	— 4	— 65	+ 260	16	4,225
35	190	—15	—295	+ 4,425	225	87,025
50	460	0	— 25	0	0	625
600	5,820	0	0	+57,220	5642	847,500
ΣX	ΣY	Σx	Σy	Σxy	Σx^2	Σy^2

$\overline{X} = 50$; $\overline{Y} = 485$; SDx = 21.68 ; SDy 265.8

$$\therefore \quad r = \frac{\Sigma xy}{\sqrt{\Sigma x^2 \,.\, \Sigma y^2}} = \frac{57{,}220}{\sqrt{5642 \times 847{,}500}}$$
$$= +\ 0.83$$

This coefficient of +0.83 implies that there is a high degree of positive correlation between employment and sales. Whenever employment increases, the sales also increase. In general the coefficients between +0.5 and +1 indicate a high degree of correlation and between—0.5 and +0.5 indicate little significant correlation. If a zero value is obtained then it indicates that there are two sets of data fluctuating completely and independently of each other and that there is no correlation between the two.

The above said analysis of correlation coefficient is not complete unless we determine the significance of it. This can be done by resorting to t test. The following formula can be used for this purpose :

$$t = \sqrt{\frac{r^2 (N - 2)}{1 - r^2}}$$

Linear Regression :

Linear regression is a line describing the relationship between any two variables on the average and may be called " the line of average relationship". In fact there are two regression lines, one for y on x and the other for x on y. In the first instance it is possible to predict the approximate value of Y, given a figure for X and *vice versa* for the regression of X on Y.

The equation for Y (unknown) on X (known) is

$$(Y-\overline{Y})=r\,\frac{SDy}{SDx}\,(X-\overline{X})$$

For X (unknown) and Y (known) the expression is

$$(X-\overline{X})=r\,\frac{SDx}{SDy}\,(Y-\overline{Y})$$

The regression equation of Y on X for the data referring to the employments and sales becomes

$$Y-485=0.83\times\frac{265.8}{21.68}(X-50)$$

$$\text{thus } Y = 10.17 - X\,23.50$$

taking arbitrary values,

if $X=10$, $Y=78.20$

if $X=20$, $Y=179.90$

The regression line for Y on X can also be found out as

$$X-50=0.83\,\frac{21.68}{265.8}\,(Y-485)$$

$$X=.08\,Y+11.20$$

These values may be used to draw the regression line on a scatter diagram (Figure 117)

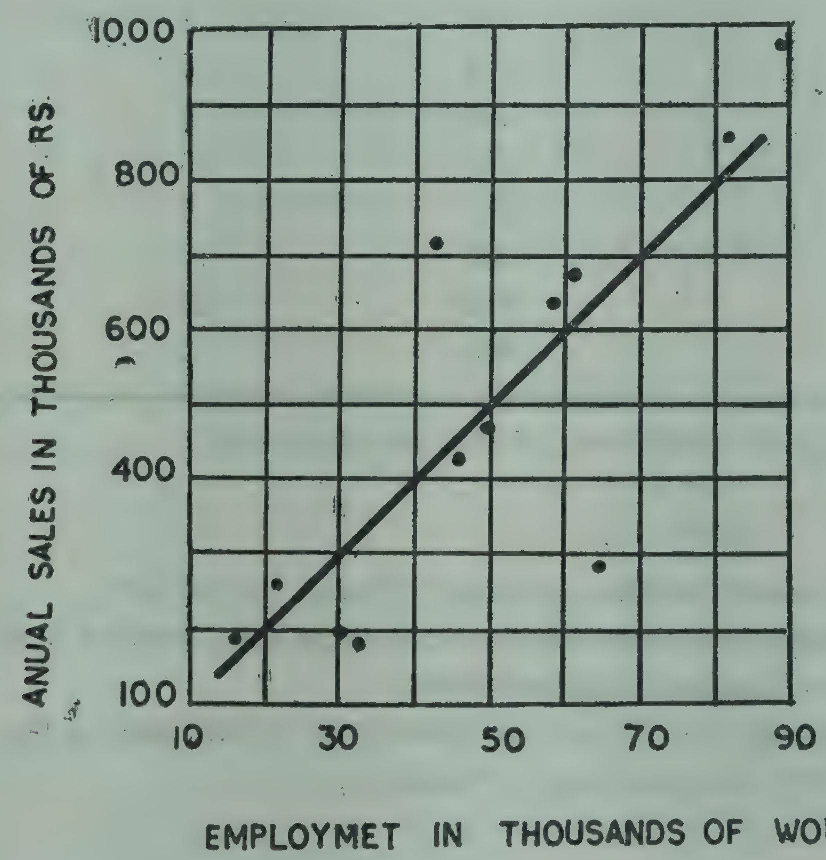

Figure 117 : A regression line.

Rank correlation :

This is another method of measuring the degree of association between two series. Its advantages are as follows :

(a) It is quick, less-laborious and useful where intensive study is not called for ;

(b) If the data are given, such as ranks, scores etc., the degree of association can be found out by this method ;

(c) This is helpful in correlating two sets of qualitative observations (poor, fair, good, superior etc.)

Now let us take the data in table 17 and rank them :

Table 17 : *Labour force and sales volume*

Size of labour force X	Sales volume Y	Rank of X	Rank of Y
16	180	1	1
22	250	2	4
31	200	3	3
35	190	4	2
43	710	5	10
46	420	6	6
50	460	7	7
59	630	8	8
61	670	9	9
65	280	10	5
82	850	11	11
99	980	12	12

The formula for coefficient of rank correlation is

$$P = 1 - \frac{6 \Sigma D^2}{N(N^2-1)}$$

where P stands for the coefficient of rank correlation.

D stands for the difference between each pair of ranks.

N = Number of paired items.

D for each pair of ranks can be found out by subtracting the rank of Y from the rank of its corresponding X (table 18).

Table 18

Rank of X	Rank of Y	D	D^2
1	1	0	0
2	4	—2	4
3	3	0	0
4	2	2	4
5	10	—5	25
6	6	0	0
7	7	0	0
8	8	0	0
9	9	0	0
10	5	5	25
11	11	0	0
12	12	0	0
			58

$$\text{Now } P = 1 - \frac{6(58)}{12\,(144-1)} = +0.80$$

Sampling Errors in correlation:

If two samples of the same size are selected from a given population randomly, they would not give the same distribution on the scatter-diagram. The r values of the two would differ from each other and none of them can be treated as perfectly reliable indication of the r that would be obtained if the entire population were considered. To determine the deviation of the r of a sample from the true r we calculate the standard error:

$$\sigma_r = \frac{1 - r^2}{\sqrt{N}}$$

Suppose the correlation between X and Y is r = .60 for a given random sample of 100 cases, the standard error:

$$\frac{1 - .6^2}{\sqrt{100}} = .064$$

This means that if r's were similarly obtained, they will fall into normal distribution with a standard deviation of approximately .064.

With the help of these methods one can analyse the data and use them for statistical mapping. Only a few of the very elementary methods have been given in this chapter. Those interested in advanced work are referred to several of the books on general statistics.

USE OF COMPUTERS

Computers can be fruitfully used in the interpretation of statistical data. Computer is a calculating machine which accepts data and instructions of variable word lengths. It processes the data according to given instructions, and gives the results in the form of numbers, words or graphic patterns. An example of the graphic pattern derived from a computer is given in figure 118.

Figure 118 : A graphic pattern derived from a computer.

Note on Figure 118

" Cambridge has been mapped according to population per acre by the Graduate School of Design's recently established Laboratory for Computer Graphics. It presents a shape reasonably familiar to all who have studied or visited the City on the Charles.

"Instead of by population density, Cambridge could have been mapped according to family income, average mortage on dwellings, racial or religious background—or according to any other available significant measure of the community and its inhabitants. This new method of graphically presenting complex mathematical and statistical data has obvious applications to city and regional planners, to urban sociologists, to all those businessmen who have tried to choose a site for a new shopping center, to sales directors of innumerable products, and to government officials.

"The new system of computer map-making was first developed two years ago at Northwestern University by Howard T. Fisher, now Lecturer on City Planning and Director of the Laboratory for Computer Graphics at Harvard, and Visiting Senior Lecturer at M.I.T. The Laboratory recently received a $294,000 grant from the Ford Foundation to support research and training in the new technique.

"The sample map shows only part of Cambridge in a series covering the entire city designed to provide greatly increased understanding of the community in which the University is principally located. The result of many thousands of calculations, the map was produced on standard equipment at the Harvard Computing Center in about a minute from 1960 census data covering population, plus area information. The darkest zone indicates the highest 20 per cent of the range of the data (58 to 72 persons per acre), while the lightest zone shows the lowest 20 per cent (5 to 18 persons per acre), with three intermediate levels falling between. The numerals, which are at the centers of census tracts, designate these density levels. The "ripples" show the Charles River, with the Xs symbolizing bridges. CEM in the upper left indicates Cambridge Cemetery—and if you look closely you can see other landmark designations such as U for Union Square, C for Central Square, H for Harvard Square, and asterisks for the boundary between Cambridge and Somerville."

CHAPTER XIV

COMPILING MAPS FROM OTHER MAPS

Maps are one of the most important sources of cartographic information. There is no doubt that each map produced by cartographers is always a new product and incorporates new data, but most thematic maps use data already incorporated in other maps. All maps must have certain basic ingredients like outline, relative location and important natural and cultural details which can be had only from topographic maps. For example. if we want to make a population map of Mysore State, we have, at first to prepare the outline map of the State. For this purpose we do not conduct original survey for we know how complicated and time consuming is the work of surveying. We therefore prepare a base map of Mysore from the maps produced by the Survey of India and other agencies. Whether we will use 1 : 1000,000 or quarter inch or one inch sheets in this process will depend upon the amount of details we would like to incorporate.

While compiling maps from other maps we face two problems (1) reduction or enlargement, and (2) generalization.

ENLARGEMENT AND REDUCTION OF MAPS

There are four ways of changing the scale of a map :

1. Geometrical method
2. Mechanical method
3. Projectional method
4. Photographic method

Geometrical method :

Geometrical method is based on the principle of similar triangles and squares. The principle of similar triangles is used in the enlargement or

reduction of relatively narrow areas, and the principle of similar squares in those of larger areas. Both the methods are very cumbersome and time consuming.

Similar Triangles method: Suppose we have a river course between A and B. To reduce it to one-third of its size, join A and B by a straight line. Select a point P at a distance about twice the length of AB. Join PA and PB and extend them to A′ and B′ if enlargement is also needed. Locate the bends and other details of the river course, and join them to P by rays as shown in figure 119. Extend these rays upto line A′ B′. Now draw a line CD within the triangle PAB parallel to AB but only one-third of its length. Line CD will also be cut by the rays emanating from P at points which have same dimensional relationships as those on A B. With the help of these points the river can be reduced (Figure 119).

Similar Square-method: The triangle method, discussed above, cannot be of much help if the area to be reduced has large longitudinal and latitudinal extensions. In this method the area to be reduced or enlarged is first divided into a convenient number of squares. Then, on a separate sheet of paper, we draw another net work of squares whose sides are proportionately reduced or enlarged. For example, if we want to reduce a map to half and the squares drawn on this map have their sides 1 inch long, the sides will be only 0.5″ long in the reduced squares (Fig. 120).

After the network of the squares is ready, the details are carefully transferred from the map, square by square. First prominent details like rivers, roads etc. are marked, the minute details are filled later.

Mechanical method:

Proportional Compass: Another, and perhaps more efficient, method of reducing or enlarging a map is the use of instruments like proportional compass, pantograph or ediograph. Proportional compass consists of two bars clamped together by a sliding screw and having a pair of needle points at both ends to act as dividers. It forms a handy aid in enlarging and reducing maps. The sliding screw can be fixed to any ratio engraved on the bars, so that the distance between the two points of the divider on one side are in desired proportion to the distance between the corresponding points on the other side (Figure 120).

Pantograph: Pantogaph is made on the same principle as the proportional compass. It consists of four tubular bars—two long ones and two short ones, hinged together at the joints to form a parallelogram. It is mounted on small wheels which give it free movement (Figure 121). It is most useful in reduction but is scarcely used for enlargement.

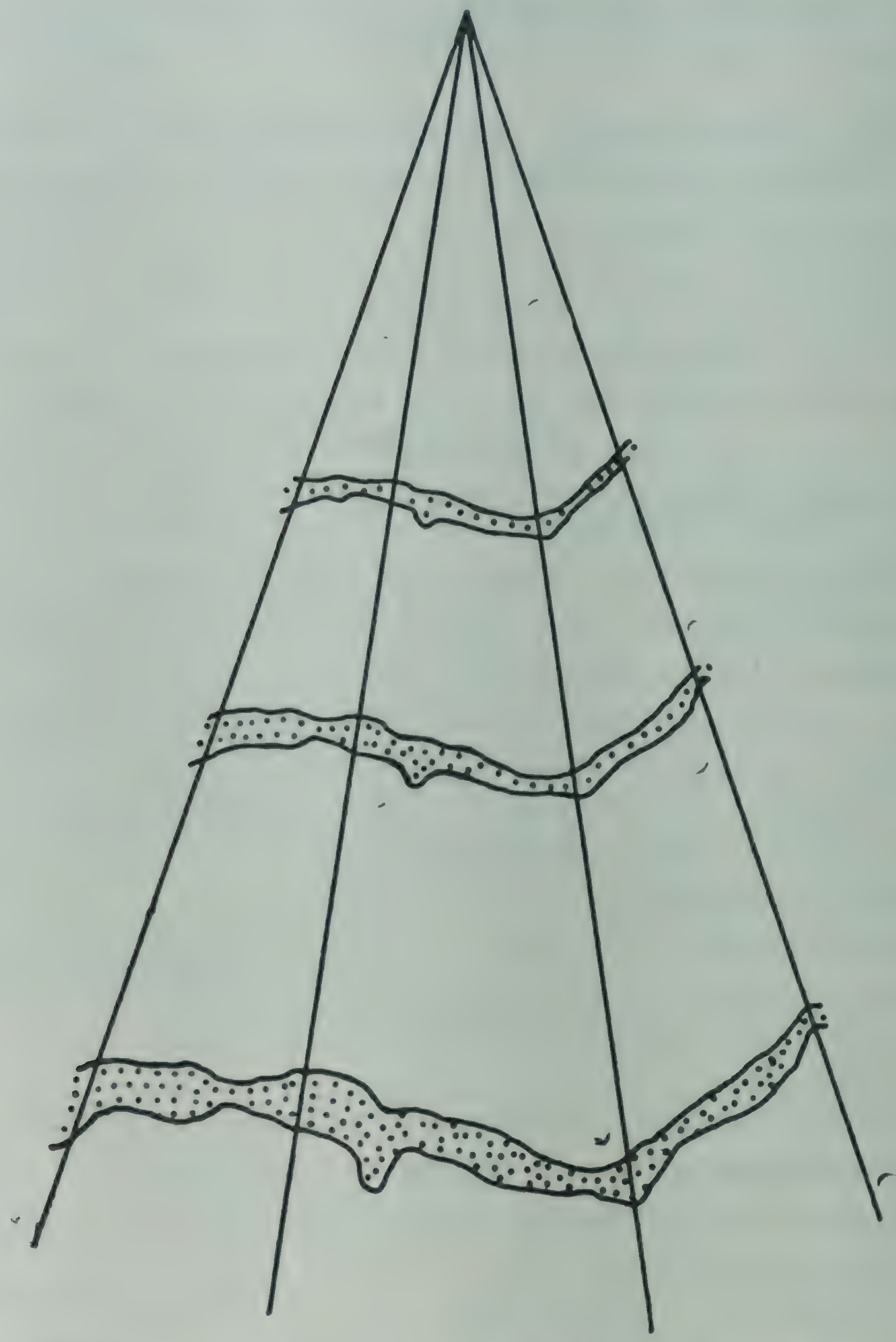

Figure 119 : Geometrical methods of reduction and enlargement
Triangle method

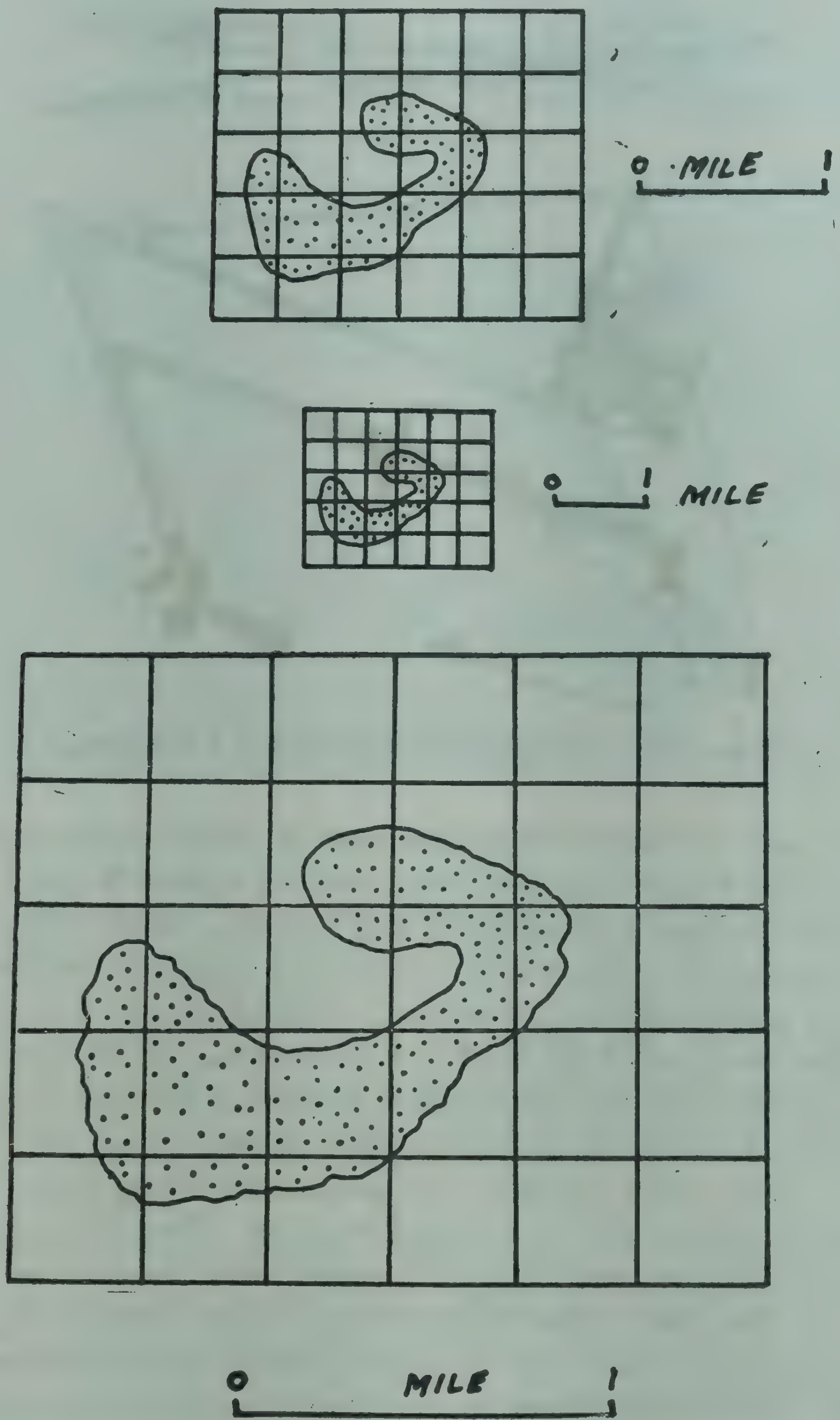

Figure 120 : Geometrical methods of reduction and enlargement
Square method.

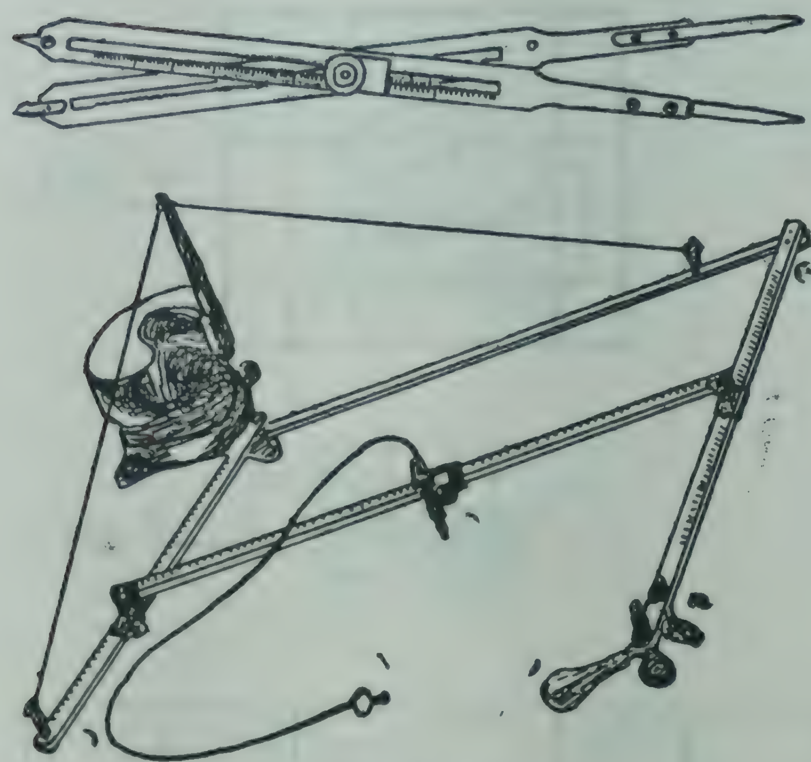

Figure 121: A Proportional Divider and a Pantograph

The most common pantograph used in India is the so-called Stanly's model. The two longer bars are equal and are marked B and C. The B bar carries an indexline and a sliding frame with socket in which is fixed the fulcrum or axis of its rotation. The fulcrum is fixed to a triangular weight or circular block having needle points at its bottom. These points keep it in a firm position. At the lower end of the bar C is a fixed socket which carries the tracer. Of the two shorter bars, the one which is parallel to bar C is marked as bar D which, like bar B, carries an index line and a sliding frame with a socket for the pencil holder. The fulcrum, the pencil and tracer holder are provided with clamping screws and are interchangeable. There is a cord-operated mechanism to raise the pencil from the paper while moving the tracer from one point to the other on the original map. Small circular weights provided with the instrument are placed on the pencil holder to vary pressure and get a sharp copy. The sliding frames may be fixed to any division or ratio engraved on their respective bars to give the necessary reduction or enlargement.

Projectional methods: Many small size maps or small areas from large maps can be projected on a paper by an epidioscope. An epidioscope has a built in mechanism to reduce or enlarge an image. It is difficult, however, to reduce or enlarge a figure to any definite scale. Distortions in scale are also

present on the margins of the enlarged figure. Moreover, only a small figure can be used in the epidioscope. There is no doubt, however, that for works where scale is not an important factor, it is an excellent device. It is inexpensive, quick and easy to operate. For accurate reduction and enlargement one may use a Kail Reflecting projector (Figure 122).

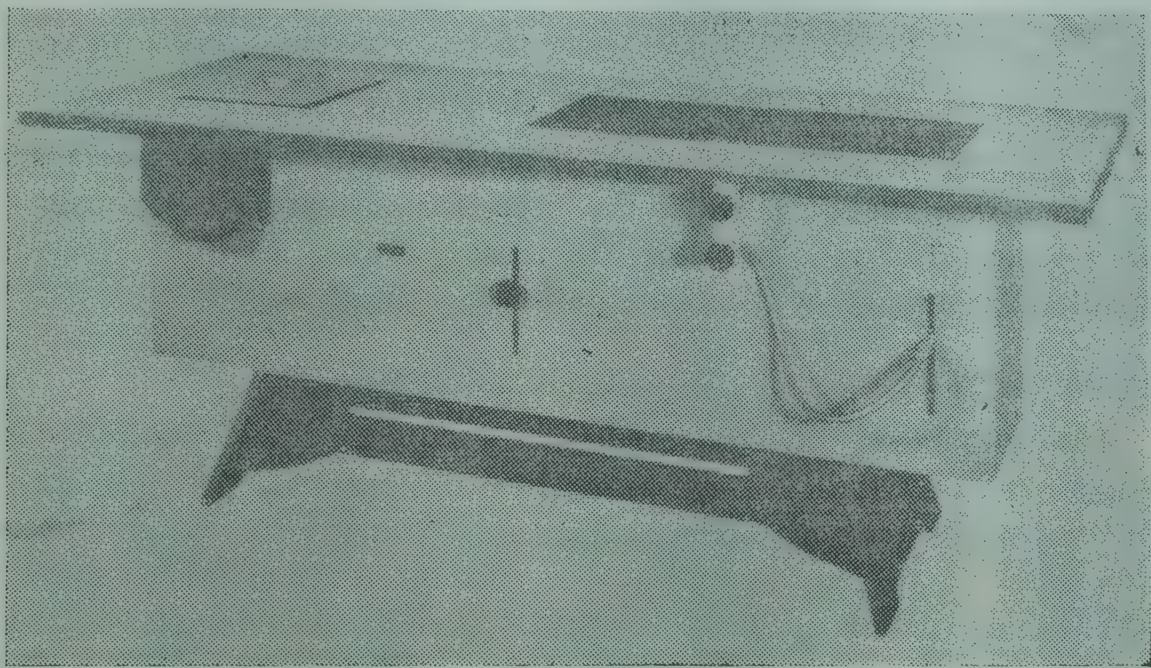

Figure 122: The Kail Reflecting Projector.

Photographic method: Photographic method of reduction and enlargement is by far the most precise but costly method. This method also can be manipulated to be used in different ways. One way is to use an ordinary camera to take photographs of a map to be reduced and then to prepare a positive slide which can be projected through a slide projector or enlarger to obtain the required size of a map. But in this process one has no control over the scale of the map projected. So the defects of projection method creep in here also.

The best photographic device involves the use of a copy camera. This is best because it is the most precise one. There are a number of copy cameras in the market. In these cameras, the enlargement or reduction is done at the time of taking the negatives. The scale of reduction or enlargement can be determined easily by adjusting the camera before taking photographs. (For further details see chapter on map reproduction).

Photostat machines can also be used to get copies at required scales. This is a camera like device with a prism fixed to its front frame and magazine to its back frame. It is mounted on a heavy pedestral stand. The original

map is placed on an adjustable copy holder which lies in an horizontal position vertically below the prism. The prism transfers the image on to a sensitized photostat paper placed in a vertical plane in the magazine. There are several mechanical devices to vary the distances of the copy holder and the magazine with respect to the prism to obtain the necessary enlargement or reduction. (See chapter on map reproduction).

PROCEDURE FOR COMPILATION

In general, the purpose of compilation is to utilize larger scale source materials covering the same area as the base, for cartographic portrayal on a different scale. The required data are traced upon a transparent medium. The resultant transparency is called a pull-up or ' guide map.'

Laying out the Pull-ups:

The first and the foremost thing is the tracing of the required details. Tracing paper or tracing cloth can be used for this purpose. But tracings made on them are subject to shrinkage or expansion. Hence heavy weight "acetate" is preferable. It is an economical and efficient medium for tracings. An added advantage of this medium is that it permits considerable amount of erasing with the help of a sharp etching knife or blade. Plastic ink is better suited for tracing than pencils because: (1) it is difficult to keep the pencils sharp, (2) the images drawn with pencil become blurred when the tracings are stacked, and (3) uneven application of the pencil results in light spots. Care should be taken in using plastic inks, as they dry very rapidly.

General Practices for Physical Details:

Relief data are always drafted in brown. While drafting the contours, one can displace them when no other adjustment to drainage or communication symbols can be made. In the process of generalization, contour curves must be maintained in order to retain the character of the landform being depicted.

Where contour lines are so close together that they coalesce, intermediate contours can be dropped. Usually, every fifth contour is taken as an index contour and the brown line drawn to represent it should be twice the weight or gauge of intermediate contours. Green ink should be used for drainage. Streams can be drawn with double lines to represent the two banks and if unity of the banks is not apparent, links should be drawn between the double lines. The general criteria for giving drainage details is to show enough so as to present the same pattern on the reduced pull-up as appears on the large

scale source. The appropriate ratio of larger and smaller streams can be maintained by using discrimination in the width of lines representing them.

General Practices for Cultural Detials:

Transportation: In preparing a guide map, road transportation comes next to drainage pattern. Red is the accepted colour for this. Only important roads need to be shown. Rail roads are drafted in black. Solid lines are intersected at specified intervals by cross ticks to represent the ties.

Built-up areas: Town patterns are generalized according to their boundary outlines if they cover large areas. The choice of towns is determined by their strategic location or importance, such as at road junctions, junctions of roads and rail roads, roads crossing streams or at gateways to other important areas. Each closely built-up areas must have a name on the final map. At times some features may have to be eliminated or shifted to provide space for lettering.

Boundaries: Boundaries of different administrative or political units should be indicated with different line symbols. When a boundary follows a single line or closely spaced double line such as a river, drain or road, it is necessary to show only every third boundary symbol placed alternatively on two sides of the line.

Selection of details:

The next important step in the compilation of maps is the selection of details. Original map from which compilations are made may consist of many details but all those details cannot be depicted on a small scale map. Some of them have to be shown in full and in popular shape, others only symbolically while still others may have to be left out altogether. This sorting out is necessary because the reduction of scale means the reduction in the length and breadth of the details to be shown and crowding together of details. The purpose of a map is to convey information. The crowding of details certainly does not serve this purpose. Hence, some of the details have to be removed. Cartographers have to use their judgement in doing so ; those items which must be there to serve the purpose of the map should not be removed.

A cartographer should think entirely in terms of how the details he is selecting would look when they appear on the reproduced map. It is necessary to choose only those details which depict the essential features of a large area. Names are not lettered on a pull-up but the cartographer must bear in mind that they will be superimposed on the final copy.

Since the symbols bear direct relationship to the scale of the source, it is quite essential to reduce them in relation to the scale of the pull-up. For

example, a circle with 0.6 inch diameter on a scale of 1:200,000 will appear with a diameter of 0.24 inch on 1:50,000 pull. In the case of solid lines, they must be heavy enough to accommodate reduction. Sufficient " light " or open space should be kept between symbols so that they do not coalesce on reduction.

Generalization :

While compiling maps from other maps, cartographers are often required to generalize the outlines and other details. Some of the problems of generalization are discussed below.

Generalization of the coast line is often a difficult task. Different maps of the same area give different coastlines yet all of them may be correct. The hydrographic charts are made with reference to the mean sea level. But the mean sea level and the actual sea level are not the same, and it is to be expected that there will be a difference in the resulting outline of the land (figure 123). In some cases the changing coastline may also pose a problem. The generalization of such water features like swamps, flood plains and tanks also is problematic. Parts of these features are under water and parts above water in different seasons. Moreover, the data given on a map are not always comparable. A map drawn on Mercator's projection gives more detailed coastline in areas away from the equator. In certain areas, like polar areas, the coastlines are not well known. One has to keep in view that the generalized outline resembles the outline shown in the map being reduced.

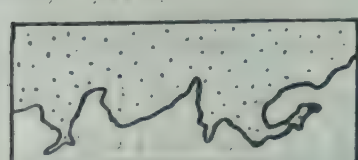

Figure 123 : Generalization of the coastline (a) Coastline on a large scale map and (b) generalized coastline for a small scale map.

Generalization of boundaries is equally difficult. On a small scale map, a little movement of the hand may give large chunks of land to the neighbouring countries or states. In some cases two neighbouring countries don't agree on their common boundaries resulting in international disputes. The adoption of any of the two boundaries may stop the entry of the map in one of the countries. A case in point is the Indo-Pakistan and Sino-Indian boundaries. Here again the cartographer has to use his judgement and discretion. At times the boundaries also change with changes in the location of certain physical features. A boundary may pass through the middle of a river. But if the river has changed its course, one side has to lose and hence a dispute occurs.

The generalization of rivers and other hydrological data also poses serious problems. When a map is reduced which of the rivers should be shown and which should be left out, is a big question. If we say that the main rivers should be shown then which one should be determined as the main river. Even if there is an agreement on which of the rivers to be shown, one has to see that the nature of the river courses is maintained. On a small scale map the differences in braided streams, intermittent streams and meandering streames, for example, may not be possible to maintain but it should be possible to maintain the larger sweeps, angles and curves. Similarly attention should also be paid to the shape of the delta or estuary of the rivers.

The degree of generalization differs from map to map ; there can, therefore, be no set standards for this purpose. Here lies the creative role of a cartographer. It must be remembered that the importance given to various details is the result of subjective analysis. A thorough knowledge of the subject matter of the map and of the area being mapped is, therefore, indispensable for good and intelligent generalization. Even in the process of direct copying from the source, one should not waste much time in drawing minute curves etc. because they will look like blots after reduction. Hence, it is far better to strive for smooth curves that suggest the details rather than mirror the images of the base source. Drafting enlarged symbols of the features that are very close together on the source map would necessitate a "piggy back" ride for one of them. But this technique is not acceptable. In order to draft the enlarged symbol in a pull, it is necessary to displace one or several of them. They, thus, remain in their true relationship but not true location or reduction.

As regards the positional priority, drainage is held to its true position followed by cultural features and contours In general, it may be pointed out that on the final compilation each feature should be shown in the same relative position to the rest of the features as it was on the original source.

Finalization :

At the final stage, a cartographer has to carefully review all source materials and preliminary compilations. Here he can compensate for any faulty generalization and can correct any error.

The pull-ups are then sent to the photo-graphic laboratory for the preparation of blue prints on which final drafting is done. We get the pull-ups printed in blue because blue is a non-photographic colour.

Before the pull-ups are sent to the laboratory for blue prints, the following preliminary identifications are marked on them.

Make size :

The dimension which the pull-up has to be reduced, needs to be given. It is given in inches / centimeters to the nearest hundredth part and is known as the *Make Size.* It is a line in the margin on which the desired reproduction size is indicated.

Labelling :

To avoid the possibility of incorrect allocations before arranging them in the completed file, one has to label all pulls in letters or figures that are large enough to be ligible after reduction. The following indentifictions should appear on each pull.

1. The geographic co-ordinates for each corner of the graticule,
2. Pull and/or base source number,
3. Number of the sheet being compiled,
4. Make size,
5. Name of the base source.

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CHAPTER XV

MAP DESIGN AND LAYOUT

PRINCIPLES OF MAP DESIGN

Among the various aspects of cartography, map design and layout is by far the most crucial and complex one. There is too much of information which can be depicted on maps, but to depict them all with clarity, simplicity, accuracy and aesthetic touch is not an easy job.

Like an artist, a map maker has to follow certain principles of visual art but unlike an artist he dose not have a complete freedom with the portrayal techniques and media. A cartographer shows his artistic talents within the framework of two types of constraints. The first results from what we call cartographic traditions and conventions; and the second from the basic requirements of maps themselves. A map is designed to serve certain utilitarian purposes. Its aesthetic value is only incidental to its utilitarian value. The artistic talent has, therefore, to function within the framework of the utilitarian requirements.

A map consists of several components or elements. Each symbol on a map is a component in itself. In order to produce a good map, it is not enough to represent each of these components clearly, simply and aesthetically. This is indubitably important but more important is the presentation of these individual components in such a manner as to obtain a good picture of an integrated whole. The individual components get their meaning only with reference to the map as a whole. Map design involves the development of this integrated plan and style of the map and its individual components, and lay out involves the arrangement of these individual components on the paper.

There are innumerable things which can be shown on maps. But everything that exists or that can be conceived to exist is not represented on all maps

Some maps do represent a variety of things—the things about which people are more intimately concerned in their day-to-day life. These maps are called the general or reference maps. Most other maps give specialized information only. Such maps are called thematic maps. In these maps only a few details are given visual prominence. The other details are either not shown at all or are shown merely to produce a background effect. The problem of making certain things visually significant without giving the impression of imbalance in the total design of a map is the most crucial problem in map design and layout. A map has to be an integrated whole, but within this whole certain components get prominence over many others, not necessarily because they are more prominent in reality but because the cartographer desires to tell more about them than about other details.

In order to prepare a balanced map and, yet, to make certain component of it visually more significant, we have to have the understanding of 1) Theory of visual perception ; 2) techniques of making things visually significant ; and 3) limitations within which cartographers function.

THEORY OF VISUAL PERCEPTION

Perception means the awareness of objects in the environment. This awareness comes through sensations like sight, sound, taste etc. One of the older theories of perception suggests that the objects which we see emit something of themselves to our eyes, to enable us to see them (Epicurean Greek philosophers). After Newton's discoveries, it was generally believed that the objects, rather than emitting something of themselves, reflect light to our eyes, very much as in a camera. This image was supposed to be the exact copy of the objects seen. Experiments later disproved this theory also. Various optical illusions were given as the basis for discarding this theory. Then came the theory which proposed that perception is an interaction between the perceiver and the objects perceived. This theory can be explained better by taking the example of the sun light falling on an object, say, grass. We see grass to be green because it absorbs all the light waves except the green. The light waves creating green are not green so long as certain cells in the retina of the eye do not interact with the light wave in certain ways to produce the experience of green. Neither the light emitted by the grass nor the censory cells in the retina, are green. It is the interaction between the two which produces green.

The most recent theory of visual perception disapproves all the above noted theories. It suggests that perception is in reality a transition and that various shapes, colours etc. that we perceive exist only in terms of the situation in which

they are perceived. It says that (1) total environment in which the object lies enters into perception as active participant, and (2) the object, if removed from the given environment, loses its whole meaning. An example will make this clear. When we look at the sunset, we do not see certain colour, lines, shapes and shades. We see the sunset. We do see the details of the colour and shapes but only sub-consciously. What we get, however, is a total visual experience. The bright colours which we see in the sunset do not bother us, but they surely bother us if we have wall papers of same colours.

The above noted shift in the theory of perception is very pertinent and relevant to map design. It, in effect, tells us that various symbols that we use in a map, acquire their desired meaning only in the context of the map as a whole. They will convey little or no meaning if they are removed from the total situation i.e. map as a whole. Further, it also indicates, that the same symbols and their arrangements cannot be used in all maps, for each map is designed to present a different situation. What is good in one map may prove to be disastrous in the others.

This, however, does not mean that individual components of a map are not important. A line, one of the simplest elements of a map, for example, can be manipulated to produce different perceptions. A line involves relationships within itself and with its surroundings. A horizontal line produces the perception of line direction. A vertical line tends to produce more tension and excitement than a horizontal line. A diagonal line produces discomfort to the observer's eyes because it lacks balance (figure 124).

The positioning of symbols in association with various types of lines produces different perceptions. For example, if a bending man is shown above a diagonal, he appears to be picking up something from the ground. But if he is placed beneath the diagonal, he appears to bend under the weight of space above him (figure 125). Several lines put together in different orders produce different perceptions. Lines forming various shapes, like squares, triangles etc. lose their existence altogether. When we see a triangle, we never perceive it to be three lines put in a certain order. We see a figure. The new theory of perception also tells us that like other symbols, colours are also seen against the background in which they appear.

When we look at a visual symbol or a group of symbols (map) we first perceive only vague shapes, colours, lines, and letterings. These symbols slowly begin to relate to one another. At first we perceive the distribution of land and water quickly if the two features are shown in a familiar way i.e. water is shown in blue colour. We take some time if the colour scheme is not a familiar one.

And we take quite much of time, if the colour scheme has been reversed and the area shown is not familiar.

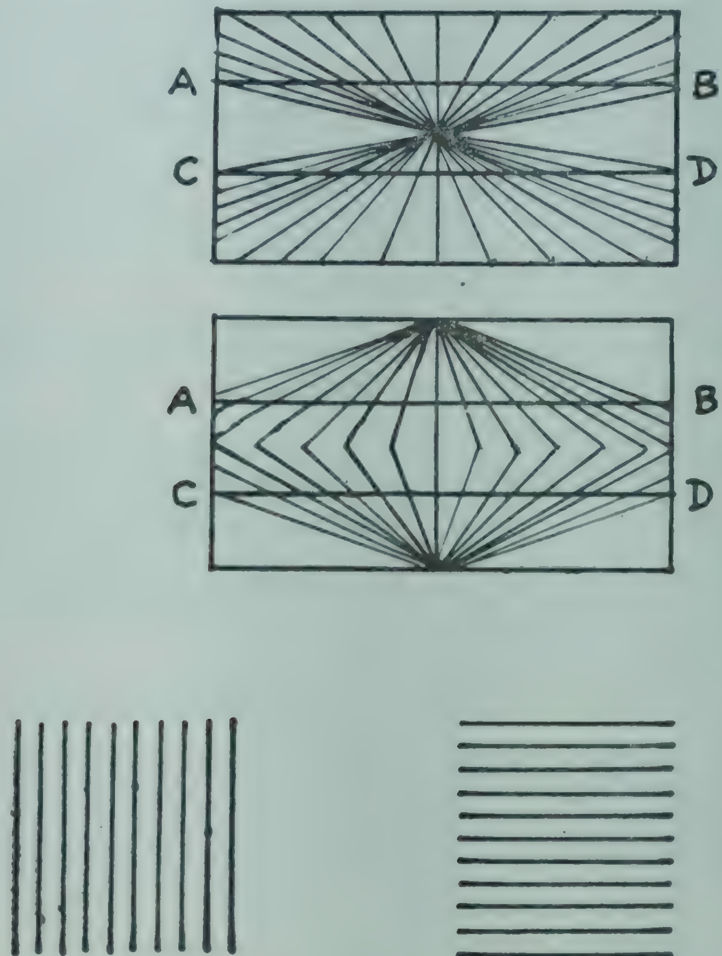


Figure 124 : Visual impacts of line orientations on perception.

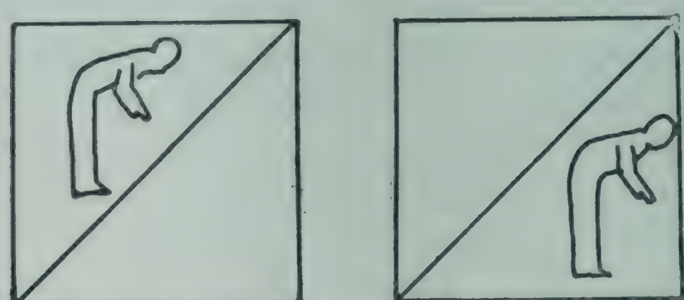


Figure 125 : Associative impacts of line orientations on other symbols.

After these broad features are recognized, the smaller internal relations begin to unfold themselves. We see the rivers, railways, roads, canals, and towns and the interrelations among them. This is just like the situation of visiting a factory for the first time. At first everything is inarticulate, but soon we distinguish various sounds, machines and sections. Finally, and after a necessary period of time has elapsed, the various parts appear to present a meaningful whole.

We get the integrated picture of a factory or a map in three phases:

1. Diffusion phase;
2. Differentiation phase; and
3. Integration phase.

MAKING SYMBOLS VISUALLY SIGNIFICANT

In the diffusion phase:

During this phase, only the visual outline of the map is seen by the map reader. Whether it is a reference map or a thematic map, the visual outline gives to the reader an idea of what is emphasized in it.

Accoring to Robinson, the fundamental elements of the visual outline are: (1) the place (2) the data, (3) the position of the data in the area and (4) the relative positions of various symbols. If the objective is to emphasize the place, it should be made distinct from the rest of the map area. This is often done when we prepare a location map. If the data are to be emphasized, the specific region where they are distributed should be emphasized and if the distribution of certain things within that area, are to the emphasized, first the area should be made distinct from its surroundings and then the region where data are distributed should be made distinct from the rest of the area. Finally, if two different data are to be given prominence, they should be made quite distinct by using contrasting colours or shades.

An arrangement of the type suggested above will make the prominent aspects of the map stand out from the rest of the data. Such an arrangement enables the map reader to catch the main purpose of the map as soon as he looks at it. The visual outline serves the same purpose as the chapter headings in a book. By making the outline prominent the map maker succeeds in transforming his product into an effective tool of visual communication.

In the differentiation phase:

In this phase of visual communication the map reader's eyes are set upon knowing further details of the data shown on the map. The data represented should have two characteristics (1) They must be correct and (2) they must be represented effectively, clearly and legibly. An effetive clear and legible representation is no substitute to correct representation. A good balance has to be struck between accuracy and effective, clear and legible representation.

Presentation of symbols: To make a map clear and legible, symbols used must be adequately differentiated from each other. For example, all lines must be drawn clearly, sharply and uniformly. To differentiate one line symbol from the other, we can either use varying thickness or varying designs of lines (figure 126).

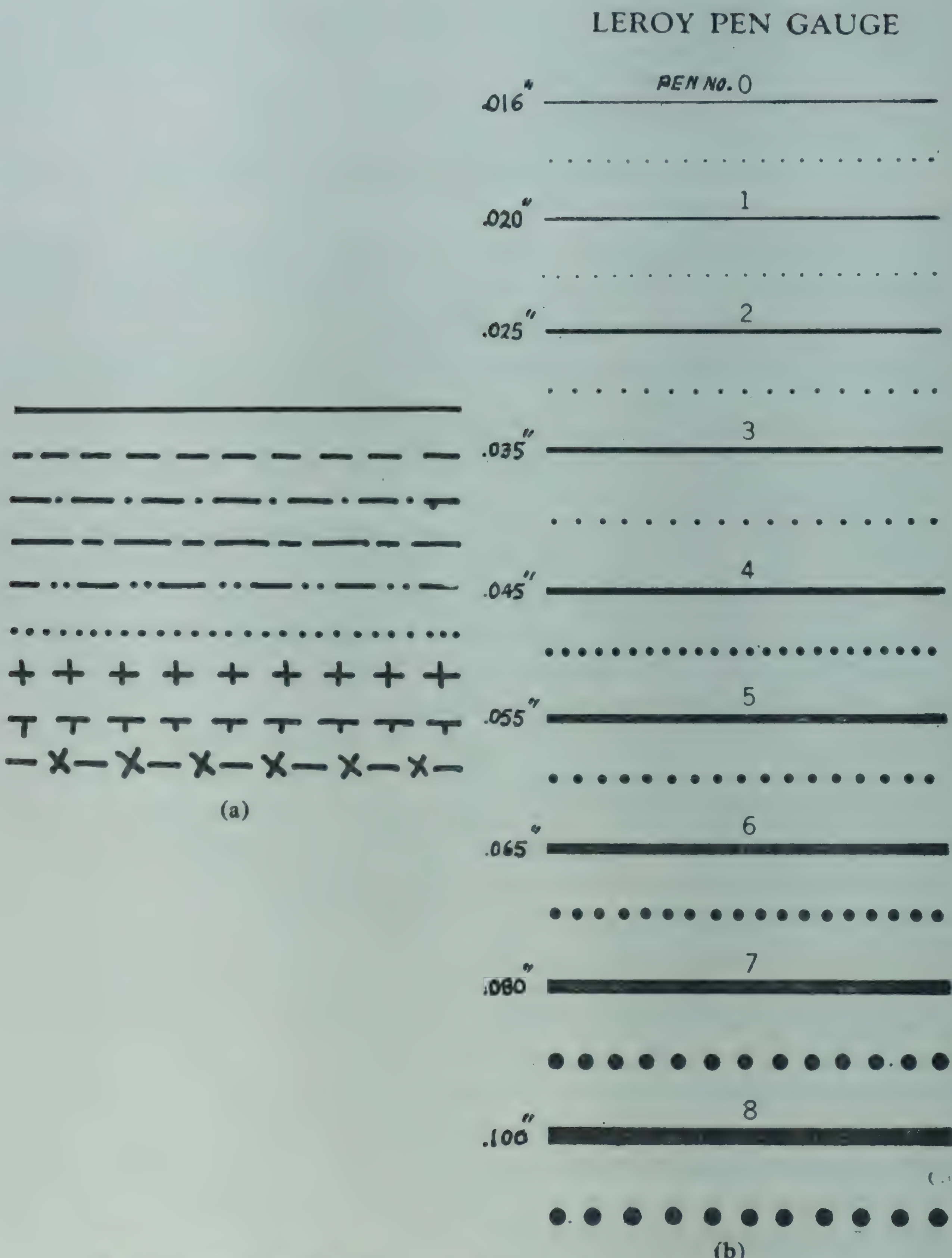


Figure 126: Varying thicknesses of lines and some line symbols.

Size and shape: The size or width of the symbols used in a map should be large enough to be visible to map readers. In this connection two facts must be kept in view. The first is that an unfamiliar symbol can be seen by a normally sighted person only if it subtends an angle of at least one minute at the eye. It means, that farther away a symbol is from the observer's eyes, larger it should be in size in order to be legible. As all the so-called normally sighted persons do not really have normal sight, it is better to keep this limit a bit higher. Experiments in this regard indicate that the angle subtended by the symbol at the eye should be between 1.75 minutes to 2.5 minutes. The following table gives the average viewing conditions :

Table 19: *Relationship between viewing distance and size of symbols*

Viewing distance	*Size of symbol (diameter width)*
1 ft	.02 mm
1.5 ft	.205 mm
2.5 ft	.04 mm
5 ft	.08 mm
10 ft	.16 cm
20 ft	.32 cm
40 ft	.75 cm
80 ft	1.5 cm
100 ft	1.75 cm

In addition to being sufficiently large in size, symbols shown on a map in conjunction with each other should be so made that they individually stand out as components of the map. They should present a good contrast with their surroundings. The contrast can be achieved by varying the shape, shade and size of symbols. How various line symbols can be contrasted with each other has already been noted. We may vary the thickness or the design of the lines for this purpose. Same thing applies to all other symbols.

Colour and shade: Colour is by far the most important single medium in map design. It enables us to create a better contrast in symbols. Used in conjuction with other graphic symbols, it makes the portrayal of data visually most interesting. It also enables more information to be fed in a map without making it congested.

In order to make an effective use of colours, we must know something about its relevant characteristics. As we know, Newton showed that colour is an ingredient of sun light. It can be separated in the form of familiar rainbow or spectrum by passing light through a prism (figure 127).

Figure 127 : Rainbow colours

The wave lengths of the seven colours which constitute sun light vary from 1/31,250 of an inch for the red to 1/62,131 of an inch for the violet. Wave lengths of less than 1/62,131 of an inch or more than 1/31,250 of an inch cannot be perceived by the human eye as colour. Many insects can perceive ultra-violet rays in the form of a colour because their sensory cells are made to respond to them as a colour experience.

The spectrum of the seven colours which we can see is derived from three primary colours. These are red, yellow and blue. These are called primary colours because all other colours can be produced by a combination of these three.

The fact that our eyes perceive only a limited range of wave lengths as colour is in no way a handicap for us, for the colours which we can perceive offer such wide ranging combinations that we cannot fall short of them. The colours perceived by us have three characteristics. These are (1) hue (2) value, and (3) intensity.

Hue is the quality which differentiates one colour from the other. In all, there are ten hues : (1) yellow-red (orange) (2) yellow (3) yellow-green, (4) green (5) blue-green (6) blue (7) purple-blue (8) violet (9) purple, and (10) red-purple (magenta). The shades between any two hues can be further subdivided into ten steps, to make 100 hues in all. Each of the hundred hues is further divided vertically and horizontally. The vertical divisions are called values. Each hue has ten shades of values ranging from white at the top to black at the bottom. Each hue is again divided into 10 shades to give the varying degrees of intensity or brightness or relative saturation of the colour area. These 10 shades vary from gray to pure colour. Thus, we get combinations to form over 5000 colours. These colours are designated to give all the three characteristics. For example Y.R. 4/3 means yellow-red of fourth gradation in darkness (value) between black and white and third gradation in briliance (intensity) from gray to full yellow-red.

Human eye is most sensitive to red, followed by green, yellow, blue and purple in that order. Certain colours like yellow, blue, green, red, white and black appear as individual colours while the others appear as mixed colours. While chosing colours for maps these facts should be kept in view.

Another fact which must be borne in mind is that colours maintain their original hue, value and intensity only when shown individually. In association with each other they tend to lose their characteristics. For example, a dark area shown next to a light area will make the dark appear darker and the light lighter. It means that by rearranging the location of various symbols with respect to each other, we can create different apparent values. The symbols, including colours, used in a map have a value rating. Whether they maintain the rated values or not will depend upon their arrangement with respect to each other and within the frame of the map.

Patterns : Patterns are also the means which help us in differentiating various phenomena represented on a map. Patterns can be and are used in place of colours, where use of colours is not possible, for reasons explained later. Patterns are made by varying arrangement of lines and dots, separately or together (figure 128). The possibilities of getting patterns of lines or dots or both are surely unlimited. But there are not more than 100 patterns which are used by cartographers in designing various types of maps. The most common among them do not exceed 25.

From the visual point of view, the dot patterns are better than the line patterns. As the lines have directions, the viewer's eyes tend to give an image of something unstable. At times they join the boundary lines, and make the letterings merge in pattern. Unless the line patterns are formed by closely set fine lines, they are irritating to the eye. As against this, the dot patterns give an indication of stability, and are pleasing to the eye.

In the Integration Phase:

The final phase of perceptual development or observation of a map occurs when various articulated elements of a map are composed into a coherent whole. A well integrated map will give sufficient material or information to produce understanding of the purpose of the map. It will be simple without ornate artistry, so that the attention of the reader is not diffused. Finally, it will evoke similar responses among many map readers.

One of the ways of achieving better integration is the positioning of various components of a map in such a way that their relationships appear logical. In a well balanced design nothing is too small, too large, too bright, or too light. The importance of each component is directly related to its position and visual signficance.

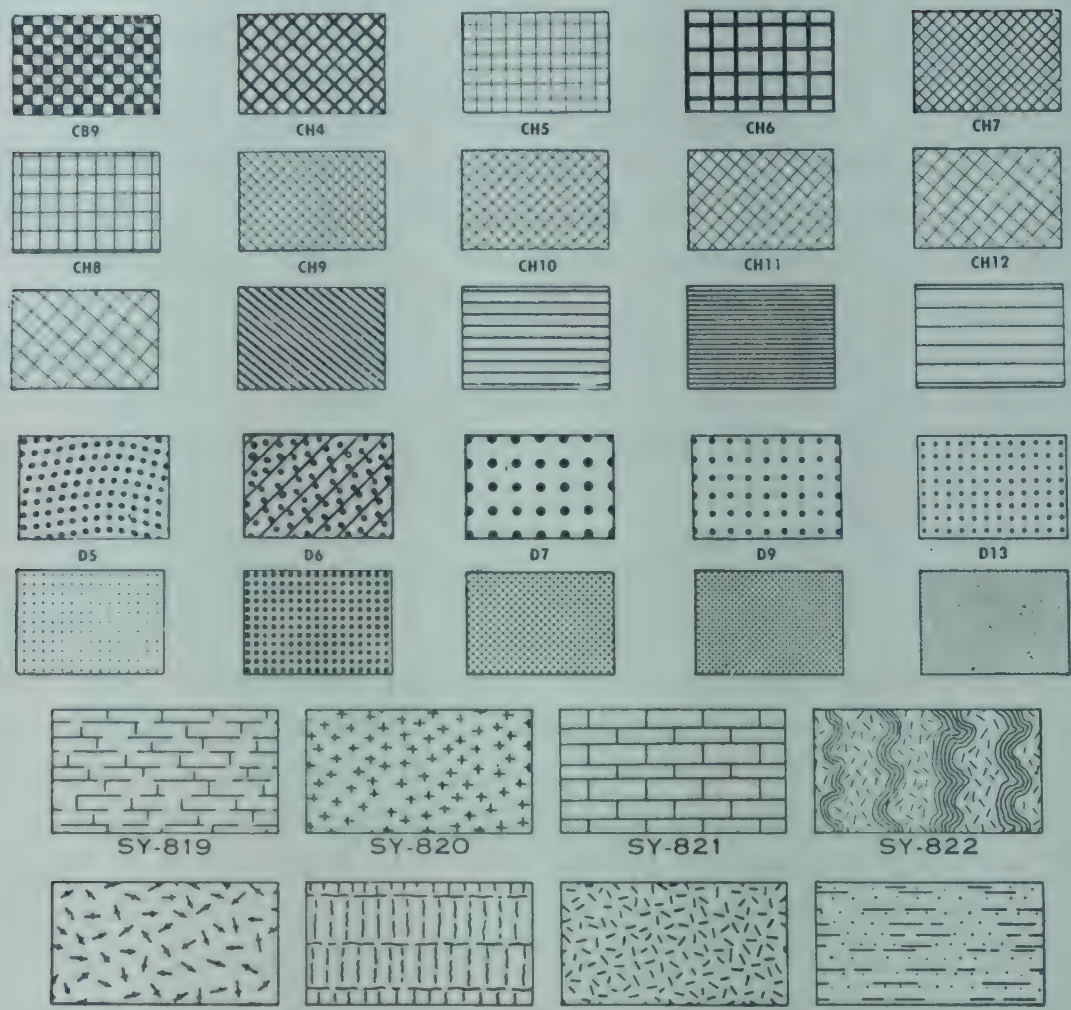


Figure 128 : Dot and line patterns

To determine whether a map is balanced or not we have to view it with respect to its visual centre which is little above the centre of the area enclosed within the neat line of the map (fig. 129). If an item is out of

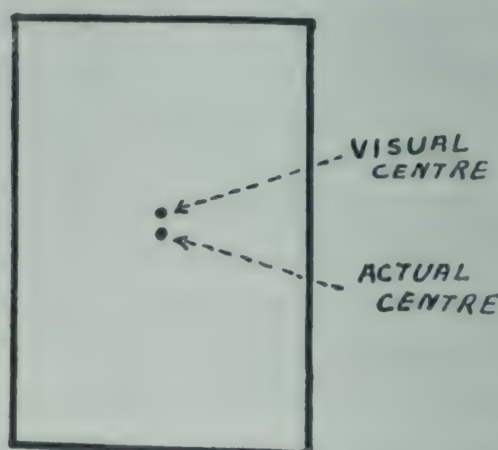


Figure 129 : Visual centre of a map

balance it may be above or below the visual plane. The aim of a cartographer is to balance the various map components so that they appear natural for the purpose of the map.

CONSTRAINTS IN MAP DESIGN

We have already noted that unlike an artist, a cartographer functions under severe constraints. Because of these constraints, many of the principles and processes of map design which we discussed earlier in this chapter, do not hold good. These constraints can be grouped together under following heads :

1. Cartographic restrictions,
2. Technical restrictions, and
3. Resource restrictions.

Cartographic restrictions :

A number of conventions have been developed in cartography, which are generally followed in all maps. Many of these conventions have now been internationalized, so that any departure from them appears to be unnatural and incorrect to the average map reader. Take, for example, the question of representing water features by blue and plains by green. We know that all water bodies do not necessarily appear blue nor are all the plains green. On our physical maps the evergreen Sunderban forests are shown as green as parts of Rajasthan desert. Supposing we try to reverse the colour scheme and show the water features by green and the plains by blue. We can imagine the consequences of it. The only logic behind the existing method of representation is, what we can say, usage.

If we compare the topographic maps published by various government agencies the world over, we will find that most of the symbols used in them are common to each other. These symbols are often referred to as conventional signs because they have been conventionalized. Whether these symbols are logical and æsthetic or not, is of secondary importance. The map users have become used to such symbols and hence their replacement will create confusion.

It does not, however, mean that a cartographer has no freedom at all. Firstly, there are only few symbols which have been conventionalized and secondly, even the conventional symbols to a certain extent can be modified in size and style to present an improved picture. For example, it is a convention to represent water in blue but there is no restriction on using flat, half-tone or any other blue. We can change the hue, value as well as the intensity of blue to see that the water features do not present an unbalanced look

Technical Restrictions:

A cartographer, while designing a map, has to work with a number of technical restrictions. Some of these restrictions are discussed below.

Publishers Specifications: Persons who approach a cartographer for preparing a map have certain set ideas about the kind of map they want. It is not uncommon to find a map lover who wants every information he needs to be shown on a single map. He gives a long list of facts to be portrayed and then tells at the end that the size of the map should not exceed, say, 8″×8″.

Maps are used for a variety of purposes. Some of them go as wall maps, many others as atlas maps, but a vast majority of them go as illustrations in various types of books. For each purpose, the cartographer has to have a different design, although the information to be given might be the same. Wall maps are to be seen from a distance of more than five feet. In these maps only outstanding features of the data are to be shown clearly, legibly and boldly. Atlas maps are to be seen from a distance of about 1.5 feet. Hence the visual significance of various objects is not based on bold representation but on contrasts created by appropriate positioning of symbols and colour schemes. The book illustrations are used in conjunction with the text material. Although each illustration should be self-contained, it is clear that it can have no independent existence. Removed from the context of the book, many of the illustrations have little or no use. All book illustrations have to be fitted within a given space. It is not too often that the size of a book is determined by the size of its illustrations.

Data, Scales, and Projections: The nature of the data, including the size and shape of the area to be represented, also influences the design of a map. For example, a map of Chile has to be an elongated one. A map of the USSR has to have large longitudinal and relatively small latitudinal extent. The nature of the data also influences the process of symbolization. Some facts can be shown by line symbols, certain others by point symbols and still others by area symbols.

Scale also influences the design of a map. On a large scale map objects can be represented in greater detail without creating cluttering. If the same data have to be shown on a small scale map, many of the details may have to be dropped in order to keep the map legible.

Projections are also important factors influencing the design of a map. Projections are of different types but there is none which can represent area, shape and direction truly at the same time. Most of the distributional data have to be shown on equal-area projections. To show correct direction, one

has to select the Mercator's or one of the zenithal projections. A cartographer has very little choice in this regard.

Reproduction processes: The reproduction technique to be used has a great influence on the design of a map. If direct contact prints are to be made, using the original as a positive, as in the case of amonia printing, the original drawing will have to be done on a transparent or transluscent paper. The reproduced map will be of the same size and design as the original drawing.

As against this, if the original has to be reduced photographically to get a negative or positive for final printing, it will have to be designed differently. A map, to be printed in multi-colour, will have as many originals as the colours. Far more data can be shown on a multi-colour map than on a black and white map. Different printing processes require different kinds and numbers of originals, which in turn require different map designs (for details, see chapter on map reproduction).

In most of the printing processes maps are drafted at a scale larger than the reproduction scale. This is done with a view to get a more refined picture of the fair drawing. It is, however, often forgotten that a well designed original does not necessarily give a well-designed print. In fact the design of such maps should have the scale of the reproduced map in view.

Resource Restriction:

The third set of restriction under which cartographers function is related to cartographic materials, instruments, time and finances. Design of a map and its quality is often determined by the cartographic materials and instruments used in drawing. Design has to vary with the quality of the paper, ink, pens, and other aids used in drawing the originals. Availability of time and finances also influences the design. A multi-colour map is a costly proposition. If finances are limited, one will be forced to think of a black and white map. Similarly, the time at the disposal of the cartographer influences the design.

SYMBOLIZATION

Every component of a map is a symbol. Map itself is nothing but a symbol. It is a symbol of symbols. Symbols are like words. As the words giving same meaning differ from language to language, so also the symbols differ from map to map. Except for a few conventionalized symbols, a cartographer has far greater freedom to develop symbols than a linguist has to develop words. Words take the meaning given by its users. Symbols take their meaning given by the cartographers.

When several words are put together in a definite order, we get a sentence. Similarly when several symbols are put together in a definite order, we get a map. Many sentences make a paragaraph. These orderly arranged symbols give a meaning which individual symbols fail to give. Symbolization and the arrangement of the symbols in a map are, therefore, crucial processes in map design. No book can be popular if the choice of words is bad. So also no map can be popular if the choice of symbols is bad.

For most purposes we can classify symbols into three types.

1. Point symbols
2. Line symbols, and
3. Area symbols

Point symbols:

Point symbols are those which give the location of an object or the quantitative value representted by it exactly at the point of its location. Point symbols are of two types: (1) qualitative, and (2) quantitative. Qualitative symbols are used to suggest the existence of an object. For example, a dot is put for a town and a cross for a hospital. Such symbols do not represent any quantitative data.

The quantitative point symbols can be used to indicate the : (1) Presence (2) Length (3) Size, or (4) Volume.

Uniform dot symbols can be used to represent the existence of a certain phenomenon in partially quantitative terms. More about this is discussed in chapter 20. The amount by which an object or idea is characterised can be represented either by bars or circles or spheres depending upon the type of data to be represented. Representation by bars indicates the length or height; by circle or squares, the size and by spheres or cubes, the volume. In this connection it may be noted that the cubes and spheres are three dimensional and, hence, they take less space than squares and circles.

Line symbols:

Like point symbols the line symbols are also used to indicate both qualitative and quantitative nature of the data. In the first category fall the latitudes, longitudes, boundaries, lines of transport and communication, streams, coastlines etc. The thickness of these line symbols is not dependent on quantitative measurements of the objects represented on the ground. In fact certain objects like geographic coordinates and coast lines do not exist in reality. The width of the transport and communication lines as well as of the streams and boundaries are highly exaggerated. They are not drawn to scale.

We do have, however, line symbols which represent quantitative values. The iso-lines of various types used to represent the physical or social data, such as contours and isarithms do represent quantitative values. Similarly the flow lines show the amount of the object represented moving from one place to another.

Area symbols :

Area symbols use the point and line symbols to give a combined effect of areal spread of the objects represented. Area symbols also are of two types: (1) qualitative and (2) quantitative.

Qualitative symbols indicate the areal distribution of a given phenomenon without showing its density. The swamps, forests, deserts, political units or soil types given on a map are mostly qualitative in nature. When symbols are used to give the relative density of the occurrence of a phenomenon whether by administrative units or by isarithmic lines, they acquire quantitative values.

FORMAT OF A MAP

All maps must show a few common components. These are title, legend, direction, scale, and source and in some cases insets. The title of a map may be placed anywhere within the neat line. Most appropriate place is the top right of the frame. It can also be placed at the top left or bottom left or bottom right. The title should include the name of the area represented, and the nature of the data shown. If the data pertain to a given year this should also be given. The title should always be given in bold and simple letters. If necessary, it can be enclosed in a box.

The legend of a map is usually placed in a corner within the neat line. The position of the legend is so selected that it does not interfere with other details. Every symbol and abbreviation used in a map should be explained in the legend.

Direction is shown in one of the corners by an arrow pointing to the north. Scales can be expressed in one or more of the several ways explained in chapter V. In an original drawn for reproduction, the scale should conform to the requirements of the printed map. If the scale is given in R.F. it should be the scale of the printed map and not of the original drawing. The best thing to do is to give a bar scale because the bar is also reduced with the original drawing. The scale of a map should be placed at a prominent place. It can be placed just below the title or somewhere at the bottom. Every map must give the source of the data used. Most of the maps we use, do not mention the

source, thus they keep the map reader in suspense about their accuracy. The source should normally be given outside the frame of the map on the bottom right. On the bottom left should be given the name of the author, publisher, etc.

In many maps it becomes necessary to give an inset map. An inset map can be used to show the location of an unfamiliar area within a relatively familiar area. For example, if a district is represented on a map, an inset map may be given to show the location of the district in the state or the country. It can also be used to give a portion of the area represented in the map in greater detail. For example, while showing the population distribution in a state, an inset can be given to show the details of the population distribution in a metropolitan region. There are many other details which can be fruitfully shown in an inset map.

The border of a map usually consists of two lines 1/4″ to 1/2″ apart. In between the two lines are given the degrees of latitudes and longitudes. The outer line is thicker than the inner line. The inner line is also called the neat line. In some maps only the neat line forms the border. The degrees are written inside the frame. The margin outside the outer line should not normally be less than 1/2″. If marginal information is also given, as in the case of the topographical maps, margins will have to be wider.

Lettering forms an important component of map design. It is discussed in the following chapter.

CHAPTER XVI

LETTERING AND TOPONOMY

Letters are verbal symbols. They form words which give us certain meanings. These letters and words have to be incorporated in the body of the map along with other symbols. Letters are conventional symbols of the linguists. We have to use these symbols as they are given to us whether we like them or not. What we can do, however, is to change the style, form, size, colour, etc. of these symbols to suit our specific needs.

Lettering has always been an important aspect of map design. In the past ornate lettering was very common. It was partly used as a device to fill up vacant spaces in the map. In those days all lettering was done freehand. Subsequently it came to be engraved. In all these processes the artistic aspect of the work was considered to be more important than its usefulness. Ornate letterings are difficult to read (Refer to figure 142).

The style of lettering has changed with the change in the printing technology and the taste of the people. At present the best lettering is considered to be one which can be read easily.

While lettering on a map, one has to decide the following:

1. Style	5. Method
2. Form	6. Position
3. Size	7. Relation to reproduction
4. Colour	8. Standardization

STYLE OF LETTERING

There are three main styles of letterings. They are (1) classical, (2) modern, and (3) sans seriff.

The origin of the classical style is Roman. In this style the proportion of thick to thin lines making the letters is not great. The strokes of the letters

have long and curved serifs. It is an ornate style and difficult to read. The modern style was developed in about 1800 A.D. It has precise geometric shapes, and the difference between the thick and thin lines making the letters is often excessive to give an unbalanced design. The lines are marked by small horizontal strokes. The sans serif style is the most modern and up-to-date one. It has no serifs at all. It gives a clear cut, new and nontraditional appearnace. It is the best style from the point of view of legibility (Figure 130).

FORM OF LETTERING

Within these styles one can develop several sub-styles or forms by changing the slant, thickness, and complexity. The style which can be considered to be good is one which is easy to read. Ornate and fancy designs are good to look at but difficult to read.

SIZE OF LETTERING

In view of the complex and varied nature of the data represented on maps, it is often desirable to use several lettering styles to create contrast. But this should not be overdone. Within the modern style, we can have several combinations by using the capital and small letters and by varying the size and thickness of letters.

The selection of the size of lettering is very important in map design. It is true that certain styles of letters are difficult to read but even the most modern and legible style will be of no use if the size is not properly selected. The size of letters is designated by points. Points 1 is equal to one twelveths of an inch. Lettering that is one fourths of an inch high is equivalent to 18 points. Perhaps point 3 is the smallest type which can be read from a distance of 1 foot. It is safer to use 4 or 5 point types (Figure 131).

Table 20 : *Relative visibility of Type size*

Size in points	Relative visibility from 18 inches
3	1.10
4	1.60
5	2.11
6	2.64
8	3.64
10	4.65
12	5.66
14	6.67
18	8.67
24	11.68

CHELTENHAM WIDE ITALIC

Cheltenham Wide Italic

GOUDY BOLD

Goudy Bold — Some classic or old style letter styles

GOUDY BOLD ITALIC

Goudy Bold Italic

CASLON OPEN

BODONI BOLD

Bodoni Bold — Some modern letter styles

BODONI BOLD ITALIC

Bodoni Bold Italic

MONSEN MEDIUM GOTHIC

Monsen Medium Gothic Italic

COPPERPLATE GOTHIC ITALIC — Some sans serif letter styles

FUTURA MEDIUM

LYDIAN BOLD

DRAFTSMANS ITALIC

ABCab12 — Text type style

Figure 130: Styles of letterings.

BY the ideal book I suppose we are to understand a book not limite	7 point
BY the ideal book I suppose we are to understand a book not	8 point
BY the ideal book I suppose we are to understand a b	9 point
BY the ideal book I suppose we are to understan	10 point
BY the ideal book I suppose we are to unders	11 point
BY the ideal book I suppose we are to u	12 point
BY the ideal book I suppose we are to	14 point
BY the ideal book I suppose w	18 point
BY the ideal book I sup	24 point
BY the ideal book I	30 point
BY the ideal bo	36 point
BY the ideal b	42 point
BY the ideal	48 point
BY the i	60 point

Figure 131 : Size of letterings.

The table 20 can be used to determine the size of letters which will give the required perception. For example, if we want to increase the relative visibility of certain letter 5 times (point 3 being the base), we will have to select point 12 and not point 15.

COLOUR AND BACKGROUND

Another way of creating contrasts and making letterings more legible and easily perceptible is to put them in varying colours and against contrasting backgrounds. Greater the contrast between the lettering and the background, more the legibility and perceptibility. Black lettering on a white background stands out at the top of the scale ; on a gray background it looks faint and unimportant (Figure 132).

Figure 132 : Letterings against varying backgrounds.

POSITIONING

Positioning of lettering means placing it in the map in relation to other symbols. The layout of letters should normally be parallel to the top and bottom of the neat line. This, however, creates some imbalances if the parallels and meridians are also shown in the map, for in many cases the parallels will not be parallel to the neat line. It is, therefore, desirable to eliminate the graticules from the land areas of the map. They can be shown by strokes along the neat line. They need not be eliminated from the water features. This should not, however, be considered to be a rule, for in many cases the graticules may have to be shown to serve certain specific purposes.

In cases where the features to be named have areal extents such as countries, mountains etc. letters should be spread to include the entire feature. They should be equally spaced and easily distinguishable. Names of the rivers should be positioned along their courses and the letters should be slanting. The alignment of lettering used for railways, roads, canals, telegraph lines, air-routes, sea routes, etc. should be the same as that of the objects. Place names should be so positioned that they do not mix up with symbols. They should be placed a little above or below on the right or left of the symbol, to avoid mix up. The titles and the legends, if put in more than one line, should

be balanced around a central line and positioned carefully. It is advisable to first write the letters on a tracing paper and to adjust the position by shifting the paper left and right.

MECHANICS OF LETTERING

There are several lettering devices. The following three are discussed below:

1. Free hand, 2. Stick up, and 3. Mechanical

Freehand lettering:

Free hand lettering is done with the help of a pen. It requires good planning. Guidelines are drawn with the help of a ruler, curve or lettering angle. For all capital lettering only two guide lines are needed but for mixed

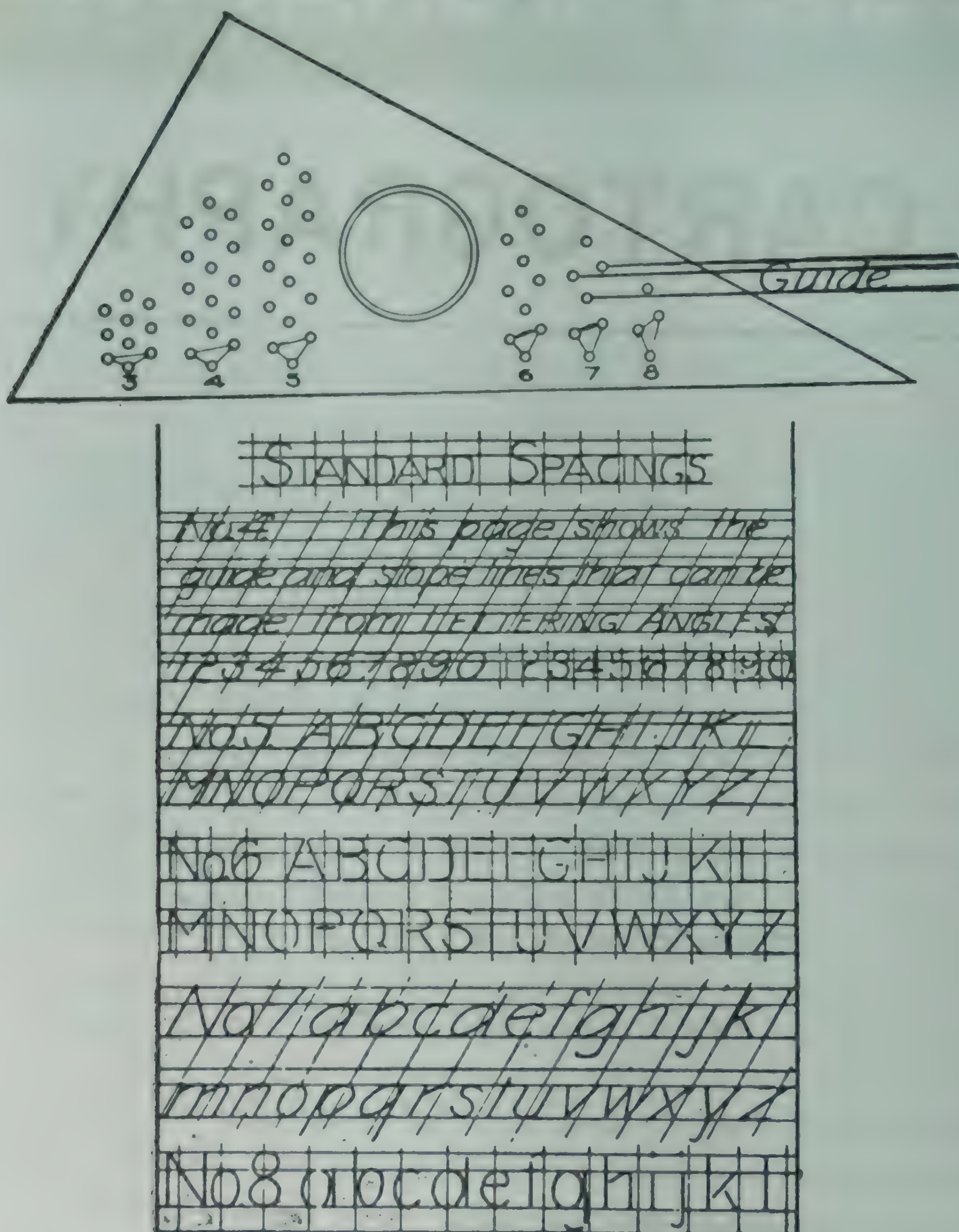


Figure 133: Freehand lettering.

letterings, three lines are more appropriate. First the letters are drawn with a lead pencil (Figure 133). Freehand lettering requires considerable practice. It is quick and more suited for maps in which letters have to follow certain crooked lines.

Stick up lettering:

To make lettering easier, one can get the terms printed in appropriate style and size. These terms can then be cut off from the sheet and placed at their appropriate positions with the help of some adhesive. The commonly used names and letters are available in the market. These are printed on wax-backed transparent papers. One can cut the individual letters or a group of letters to build desired terms. (Figure 134).

Figure 134 : Stick-up lettering

Mechanical Lettering :

Mechanical lettering is one in which instruments are used to control the size, style and thickness of letters. Following are the most commonly used devices. (1) A *Uno* pen consists of a pen attached to a small tube in which the ink is fed. The size and style of letters are determined by the

templates in which the letters are stencilled. (2) *Leroy Set* is an American product. It contains a scriber to which a pin and a pen are attached. The pin moves along a groove in the template and the pen gives the required letters. Templates of a variety of letter styles and symbols are available for this purpose. (3) *Varigraph* is the most mechanized of the lettering devices discussed here. It also consists of a template with engraved letters and a stylus. Its functioning is based on the principles of a pantograph. Adjustments to make the letters large, small, elongated etc. are possible (4) *Wrico* uses stencils as in the case of the UNO pen but the pen is of a different type. (Figure 135)

A B C D

Figure 135: Lettering devices. (A) Rapidograph. (B) Leroy. (C) Wrico, and (D) Barch-Payzant.

While selecting the size and style of lettering, it must be kept in view that the letters are also reduced with the rest of the symbols drawn on an original. They should be so selected that they will be legible in the printed map.

GEOGRAPHICAL NAMES

As already seen, lettering on maps is not as simple a job as it appears to be to an average map reader. It is a complex process and requires planning and creativity. This complexity is further increased by the fact that it is not always easy to find out the standard names of places or feataures depicted on a map.

Attempts to rationalise and standardise geographical names have been made for nearly 100 years. The International Geographical Union took this matter up in 1872. It has not, however, proved to be an easy task and the recommendations of the Union have been disregarded by almost all the member countries.

The problem involved in the standardization of geographical names can be gauged from the following example. In the 1930s a river was discovered in the western half of New Guinea. It was named after its discoverer as Father Le Coq D'Armandville River. The Popuans of New Guinea could not make either head or tail of it and continued to call the river 'The Broad River'. The principle of giving local names (advocated by the IGU) had been disregarded in this case.

The irrational changes in place names are only too common. In the USSR almost all the names given to commemorate the Czar were changed to commemorate Lenin or Stalin. One extreme example can be given again from New Guinea. Upto 1957 the capital of Dutch New Guinea was called Hollandia. After the Dutch withdrawal in 1957, it was renamed as Kota Baru. Subsequently it was renamed as Sukarna Pura. Now it is called Ayapura.

There is also the problem of disparity between the official names and the popular names. For example, Banaras in U.P. is now officially called Varanasi but the people call it either Banaras or Kashi. Duplication of place names is another problem. Many of the names are too often repeated in the same country. There are so many Washingtons in the U.S.A.

It thus appears that it is difficult to standardise geographical names unless all the member countries adhere to the principles laid down by the I.G.U. in this regard. A cartographer has to use his judgement in determining the authenticity of place names. It may involve considerable amount of library and at times even field research.

CHAPTER XVII

MECHANICS OF MAP CONSTRUCTION

The emphasis given on map design in the pervious two chapters may give the impression that a well designed map will necessarily be a well done map. A well done map should not only be well designed ; it should be well drawn also.

Drawing or drafting of maps requires some artistic skills. And artistic skills can be acquired only by regular and patient practice. Those who do not posses patience, cannot become good draftsmen. Patience and practice are not all. The draftsmen must also know the use of proper tools at the proper place and in the proper condition.

Some of the most commonly used drawing materials, tools and equipments are discussed here. Wherever necessary, the technique of handling them has also been explained.

DRAWING MATERIALS

The consumable materials needed in drawing operations are called drawing materials. Such materials consist of drawing surfaces, inks, pencils, plaster of paris, stick up letterings, colours etc.

Drawing Surfaces :

Drawing surfaces may be drawing paper, cardboard, plastics paper mounted on zinc or alluminium sheet, wall etc. The selection of the surface is determined by a variety of factors, the important among them are :

(1) Stability : Most drawing papers shrink or expand with changes in temperature and humidity. This makes it practically impossible to maintain the scale of the map and to register several plates. For instance, we draw a map on the scale of 1 inch to 4 miles. When we reduce it to half, it will show

a scale of 1 inch to 8 miles. But if the original drawing of the map has shrunk or expanded, the reduction of the size of the map to half will not give the scale of 1 inch to 8 miles.

Another problem associated with the shrinkage or expansion of drawing paper is that of registration. For colour reproduction of a map, we have to draw a separate original for each colour. These originals are then used to prepare plates for printing. Because of the changes in weather conditions each sheet will undergo change in dimensions which may vary from sheet to sheet. While printing a map, the printer has to see that the impressions from each plate fall exactly at the places they should. This can be done only if the corner marks (registration marks) on all the plates coincide with each other. If they do not coincide, the impressions will either leave a white line in between two colours or will extend to adjoining areas. Drawings should, therefore, be done on stable surfaces, such as paper pasted on zinc sheets.

(2) Ink adherence : Quality of the drawing paper determines its capacity to take ink. Some papers are porous and hence soak ink and diffuse it through fibers. Such papers produce poor drawing. There are others which hold on the ink to give a sharp image.

(3) Translucence : Translucence is essential for making tracings and also for making originals for direct contact prints. Tracing papers and cloths are translucent. It is easier to register originals drawn on tracing paper.

(4) Surface quality : If the surface is rough the drawings can not be smooth. The surface of the paper should be smooth and strong enough to take erazing. Paper should also be good to withstand repeated rollings and unrollings.

(5) Reaction to Wetting: While drawing the originals we have to use wet inks or colours. At times these inks have to be spread over large areas. There are papers which curl with wetting. Such papers are not suitable for this type of drawing. Most tracing papers and cloths get curls on wetting.

Before starting the drawing of a map, the cartographer must know well the materials with which he has to work. For most drawings, opaque paper of smooth surface with good thickness and weight is good. In many advanced countries, plastic sheets specially meant for this purpose are used. These sheets last longer. Moreover, they are stable and maintain smooth surface. The disadvantage is that in some cases ordinary drawing ink does not adhere to it. For pencil drawing, ross board is preferable. It has grained surface which gives shades of colours while drawing with a lead or carbon pencil, or crayon.

Ink :

The standard black ink for map drawing is the so-called Indian ink. Modern Indian ink is a permanent suspension of fine carbon in a liquid medium. It dries dense black which is very important for reproduction and is waterproof. While using this ink, it should be kept in mind that drawing surfaces easily pick up oil substances from the hand. The ink will either not adhere or skip the oily surface. For photographic purposes all ink work should be absolutely opaque back. For a drawing to be reproduced photographically, white opaque paint or ink can be used for corrections. This should not, however, be done on drawings which are to be used for direct contact printing.

Tints and Patterns :

A number of patterns formed by lines and dots are printed on transparent film with adhesive backing. The American brand of these patterns is known as 'Zip–A–Tone' and one of the Indian brands is known as 'Pal–Tones'. These printed patterns can be pasted at appropriate places and thus the laborious process of drawing patterns can be avoided. (See figure 128)

Colours except the red are not used in original drawing. Red can be used because it reacts like black in photography. Black, however, gives the sharpest image.

Pencils :

In the preparation of original drawings, pencils are indispensable. The leads of the pencil range from soft to hard. For most cartographic work 4 or 5 H is the softest practicable. Coloured pencils are very useful in preparing guide maps.

DRAWING EQUIPMENTS

Some of the equipments used in map drawing are as follows :

1. Drawing board or table
2. Drafting machine
3. Tracing table
4. T-square
5. Straight edge—12″ scale and a slide rule
6. Curves of various types.

Maps are usually drawn on drawing tables manufactured specially for drafting purposes. A drawing table consists of a drawing board which is made of soft wood. A drawing table with a board measuring at least 24″ × 18″ is preferable. Drawing tables have mechanisms for adjusting the height as well

as the tilt (Figure 136). The drawing paper should be affixed to the board either with a tape or thumb tacks. The later leave holes and hence should be fixed only on the extreme corners. They also obstruct the movement of the T-square. Tapes are therefore preferable.

Figure 136: A Drawing Table

There must be a drafting machine in a drawing office. This machine is fixed to a drafting table which can be adjusted in slant. It swings freely on an arm. It is designed to keep the table in parallel position wherever it may be placed. The machine is very useful in straight line drawing works (Figure 137).

A special kind of table called tracing or light table is a must in a cartographic laboratory. It is used in tracing on an opaque surface. It differs from an ordinary drawing table in that its surface is made of glass and not of soft wood. The glass is illuminated from beneath.

A table can also be custom made which combines the functions of a drawing and a tracing table. In the board of the table an opening of, say, 12″ × 9″, can be made to fix a glass.

Figure 137 : Kilburn's Drafting Machine

All tables and drafting machines must be properly lighted. Cartographic work puts lot of strain on the eyes. The lights should be such that they do not leave shadows and are adjustable. It is desirable to use fluorescent lamps.

A T-square and a set of triangles are used in line drawing work. T-squares are made of metal or solid wood. One with transparent plastic edges

is better, for it enables the draftsman to see the drawings below. It slides up and down the side of the table or board. The triangles help in drawing vertical lines with varying slants.

The curves of various types help in the drawing of curved lines. For smaller and sharp curves, a set of 'French Curves' is enough, but for large curves one has to take recourse to railway curves or spline with weights. Magnifying and reducing glasses are useful in judging the look of the drawings at various scales of reduction and enlargement (figure 138). Stencils of symbols of various types, if at hand, can help in quick drawing of symbols.

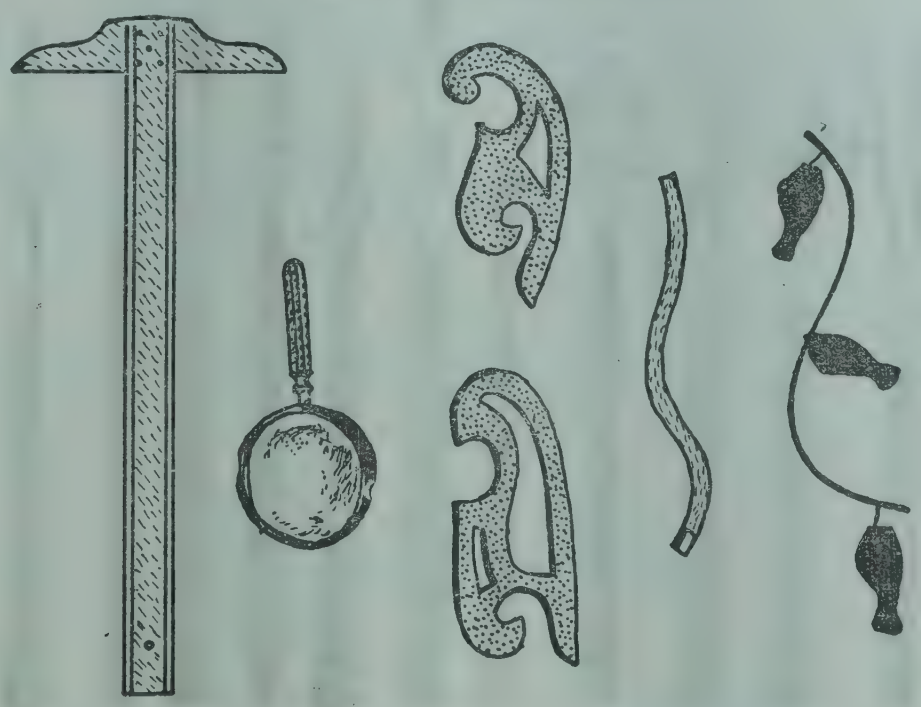


Figure 138 : T–Square, magnifying glass, curves, adjustable curve rule, and spline.

DRAWING INSTRUMENTS

There are a number of drawing instruments which must be had. One can get them in a drawing box. It is better to have a complete set, because the case in which the instruments are kept provides a convenient storage place. The basic instruments consist of (1) pens (2) compasses, and (3) dividers.

Pens :

The most common pen used by a cartographer is a 'crow quill' pen. It is a fine point pen and is used for fine drawings. It must be mentioned, however, that the use of a crow-quill requires lot of training. For thicker lines, there are a variety of pens which can be used. The important among them are (1) ruling pen and its variants, (2) leroy pens (3) UNO pens (4) Payzant pen and (5) Graphos. The graphos are like fountain pens and hence are easy to handle (see figure 135).

The most versatile pen is the so-called ruling pen. It is the most commonly used instrument (figure 139). It has two blades which can be brought closer with the help of a side screw, Thus the lines of different thicknesses can be made with the same pen. It requires frequent cleaning as the ink clogs in between the blades. Some ruling pens have their blade assembly fixed on a swivel. These are used in drawing curved lines such as contours. Pens with two sets of blades make the so-called road pens. Road pens are used in drawing parallel but swinging lines (figure 139).

Figure 139 : Ruling pens.

A leroy pen comes with leroy lettering set. It can be bought also separately. It has a cylinder with a point and ink is fed through a opening in the cylinder. The cylinder is attached to a holder. Leroy pens are numbered from 0000 to 8. Each number gives a constant width of line or dot, and variation in pressure does not affect the thickness of line. It is specially useful for those who do not have a steady hand while drawing.

The Barch-Payzant pen is also designed for lettering. It is useful in drawing uniform lines and dots. The speed ball pens have different shapes of nibs to give different kinds of lines. These are cheap and easy to operate, The graphos are like fountainpens.

Compasses and dividers :

Compass is used in drawing arcs and circles and dividers are used to lay out distances. A compass is a divider with one leg fitted with a holder for

pencil or ruling pen. Proportional dividers have two sets of needle points one at each end (fig. 121). Its mechanism and use has been explained earlier.

There are several other types of compasses. For making big circles, we have the beam compass and for small circles or round dots we have drop-bow compasses (figure 140).

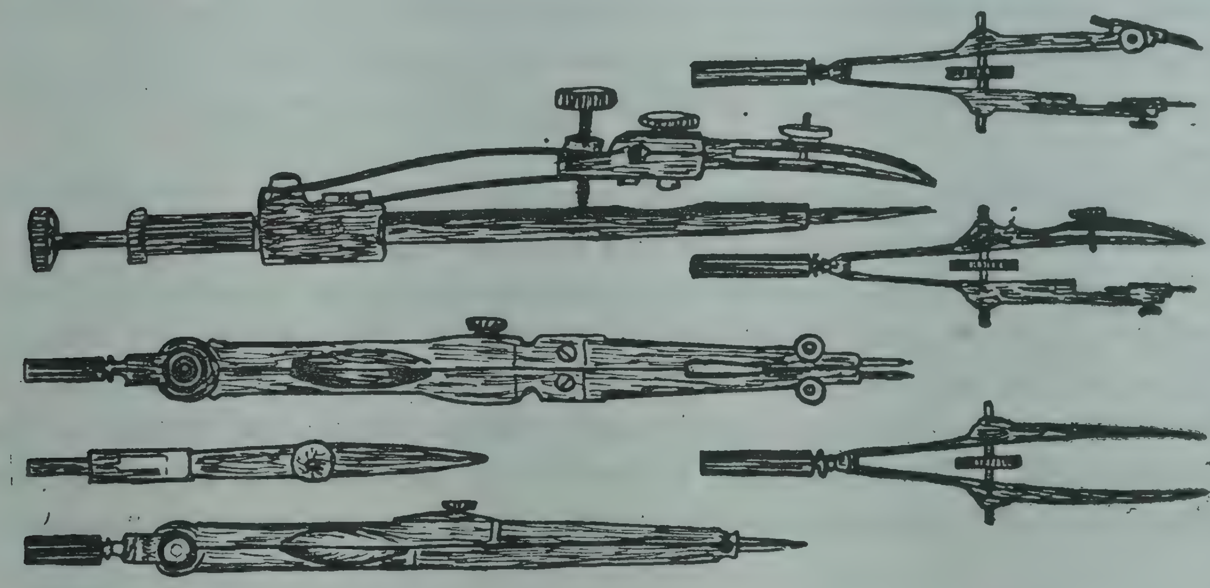


Figure 140: Bow compasses, dividers and Drop Bow compass.

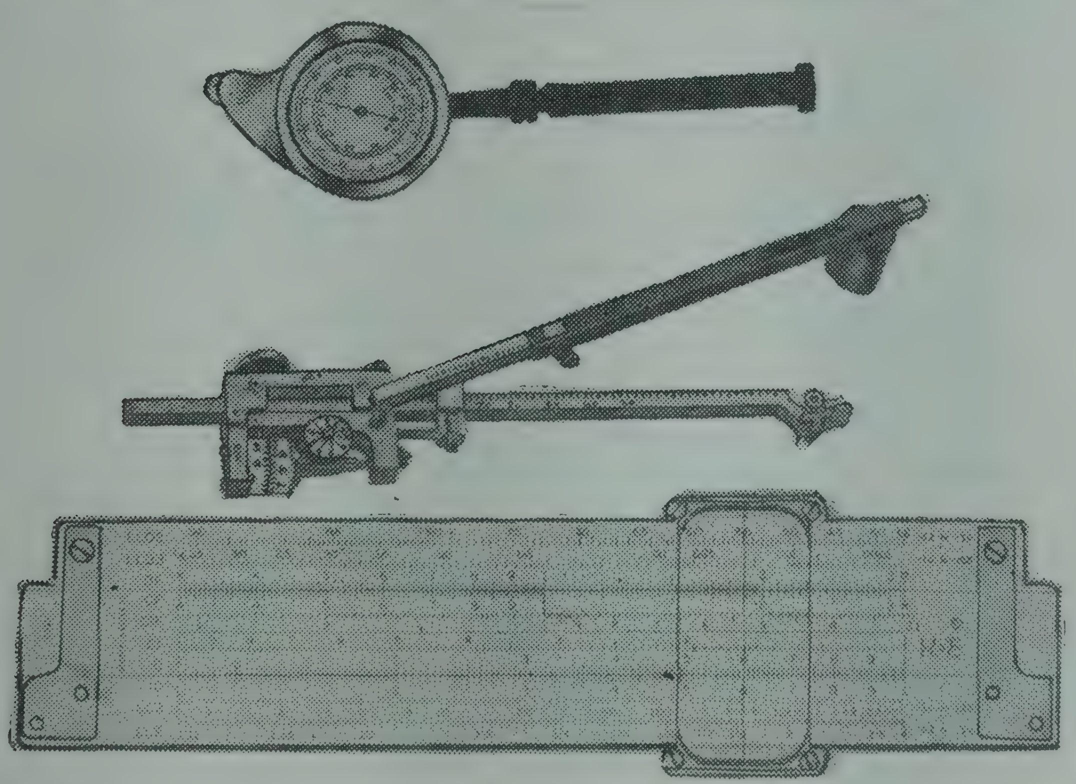


Figure 141: (a) Rotameter (b) Planimeter and (c) Slide rule.

The other important instruments are (1) rotameter (2) planimeter and (3) slide rule (figure 141). A rotameter is used for measuring the length of a

curved line ; the planimeter is used to measure area ; and a slide rule is used for quick calculation.

DRAWING AN ORIGINAL

Patience and perseverence are the two qualities that a cartographer must possess in order to be successful. There are very few short-cuts in cartographic drawing. It requires patience to watch oneself working for hours, yet, visibly producing very little. This aspect is scarcely appreciated by a map user. He is unable to realize the amount of thinking and effort that goes in making a map.

Much of the cartographic work consists of line work. A regular line is drawn with a line pen held against a drawing edge such as a T-square or a curve ; conversely most irregular lines have to be drawn free hand. While drawing a line the pen or the pencil should be held against the drawing edge in such a way that it remains perpendicular to the plane of drawing. When kept in this position, it will keep a wedge between the bottom of the edge and itself. This is necessary to stop the ink from running under the edge of the guide. This also allows the cartographer to see the line as he draws it.

CHAPTER XVIII

MAPPING THE TERRAIN

Since the early days of cartography, the depiction of terrain on maps has posed special problems. As against many other visible features of the earth's surface, terrain has three dimensions i.e. length, breadth and elevation. Because of the difficulties in depicting the third dimension on a two-dimensional surface, early cartographers took note of only two dimensions. They depicted mountains as piles of crags and the mountain ranges as arrays of sugar loaves (Figure 142).

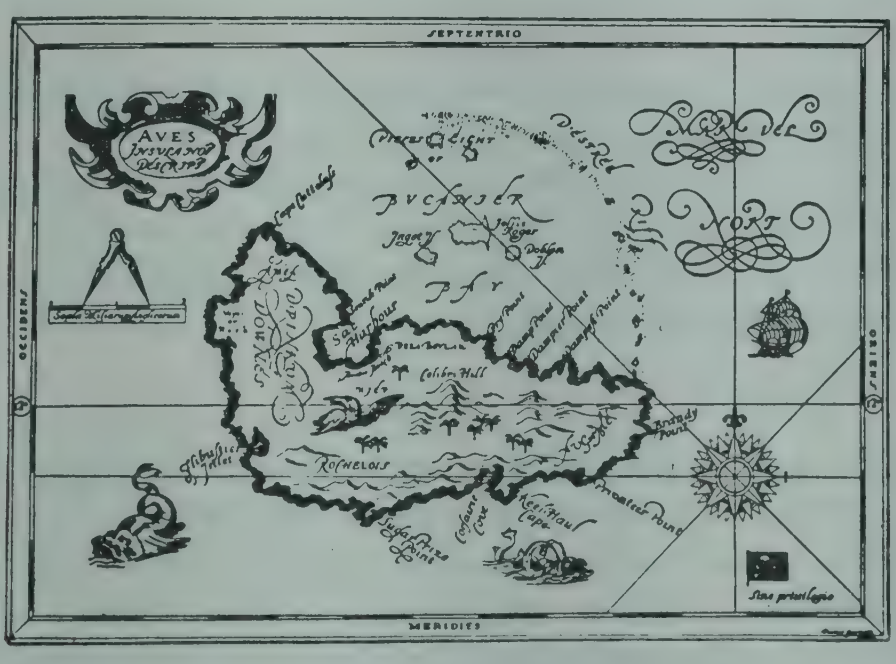


figure 142: Depiction of Terrain in early times

The pictorial depiction of terrain was resorted to due to two reasons: firstly the elevations of the mountains were not known as accurately as their lengths and breadths, and secondly a suitable symbol which could show up the

third dimension was not developed. It was only after modern surveying could give elevational data correctly, that the third dimension started appearing on our maps.

There are some unique characteristics of the third dimension which call for special techniques of cartographic representation. Firstly, it is a continuous phenomenon. Height (positive or negative) is universal. Secondly, it is more intimately known than other phenomena.

Representation of relief on large scale topographical sheets is relatively less problematic than its representation on small scale maps. On large scale maps the symbols selected appear natural and are measurable. But what is measurable is not always effective visually. The use of colour makes symbolization a bit easier. But the problem remains unresolved on small scale maps. The representation of terrain on small scale maps involves the problem of generalization of landform data. It also involves the creation of a balance between terrain and other details so that one does not overshadow the other. The representation of landforms on wall maps requires techniques which keep the slope, relief, elevation and direction clearly visible from a distance.

METHODS OF REPRESENTATION

Spot-heights:

When heights are marked on the map by numerical values (feet, meters etc.) at appropriate locations, they are called spot heights (refer to figure. 145). The chief merit of this technique is that it provides definite and precise information. Spot heights, however, fail to give any visual impression of the relief pattern. They can, therefore, be fruitfully used only in conjunction with other cartographic techniques.

Hachuring :

In 1799, a kind of flow-line symbol called hachure was suggested by Lehman, an Austrian army officer, for the depiction of terrain. It consists of a set of finely drawn disconnected lines. Each line follows the direction of the slope and varies in width as well as length. When so many lines are drawn close together, they collectively show the slopes and the ups and downs of the terrain. To highligtht the relief, the hachure lines are thickly and closely drawn on steep slopes and are thin and widely spaced on gentle slopes. The relatively level areas, whether forming a plain or a plateau, are left blank (Figure 143).

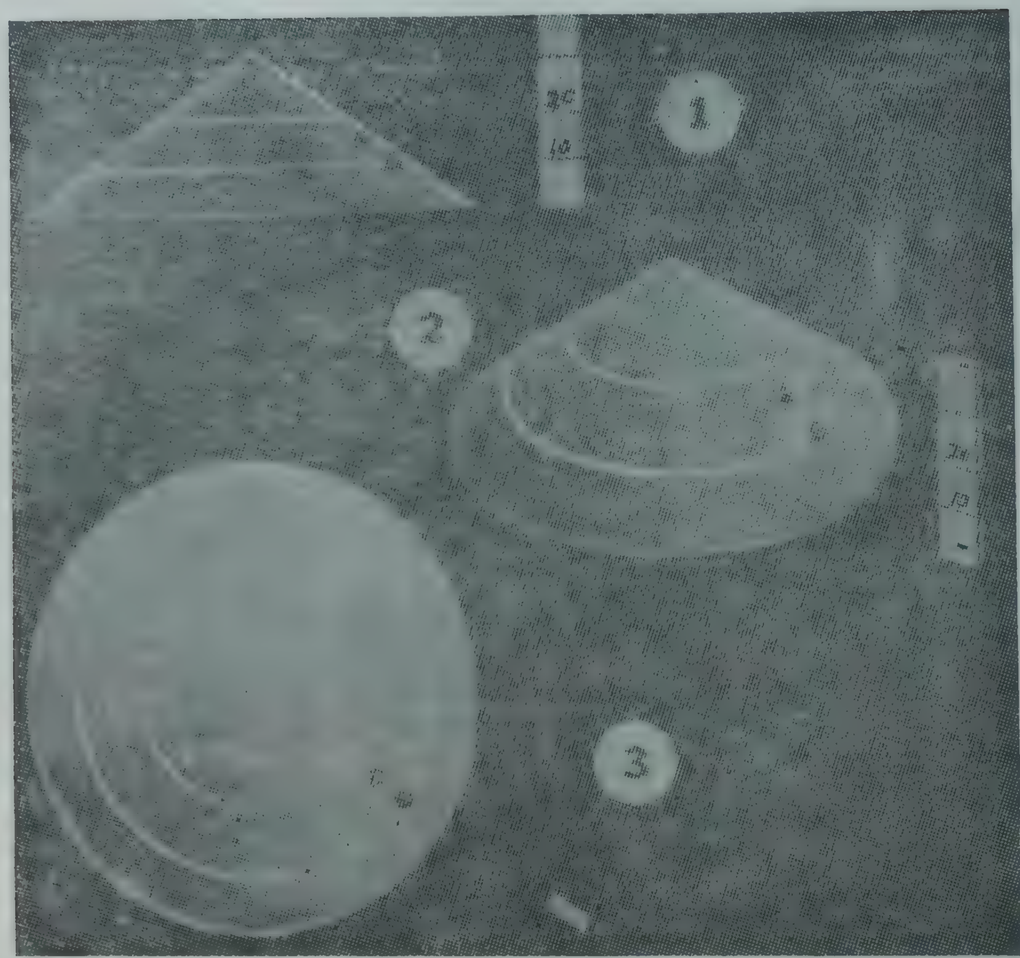
Figure 143: Hachuring

Hachuring was a very popular device among the eighteenth century cartographers. The drawings were made artistically, but they did not prove effective in portraying the terrain on small scale maps. They looked like 'hairy caterpillers'. But on large scale maps they turned out to be tolerably good.

Contouring :

Another line symbol called contour was also invented during the first half of the eighteenth century. A Dutchman named Cruquius appears to be the first to use this technique in 1730, a little before the first use of hachure. It was, however, not before late nineteenth century that it became a common method of depicting relief on topographical maps.

Contours are isarithms which connect points of same elevation. The isarithm is a general term. Its origin as well as the basis can be traced to contouring. The elevation of points used in the drawing of contour lines is measured with respect to a datum level. If we join the points which give the datum level, we will get a contour of zero elevation. Moving up or downwards, we can derive contours of various elevations in the same way. When we draw successive lines of equal elevation at a given interval and view these lines vertically, we get a contour map of the area The principle underlying contouring are best illustrated if we imagine an island amidst an ocean whose level fluctuates to submerge and then uncover the island. If we draw successive lines along the water levels at different times, we will get the contour lines (Figure 144). A cow represented by contour lines is also shown in this figure.



(a)

(b)

Figure 144 : Conecpt of contouring (a) cone viewed horizantally ; from 45 **degrees,** and vertically and (b) a cow represented by contours.

Bases of contouring: Looking at the relief map of an area, we tend to conclude that contours give that exact elevation of the points through which they pass. This is not a correct notion. Any line is a linear assemblage of innumerable points. So is a contour. But only a few of the innumerable points which constitute a contour are determined by actual measurements. The direction of a contour connecting any two measured points, is estimated with reference to local relief. The selected points through which the line joining the two measured points passes are presumed to be at the same elevation at which are the measured points. In other words, we assume the existence of a statistical surface. The points which can be selected for actual measurement constitute only a sample of the total 'universe'.

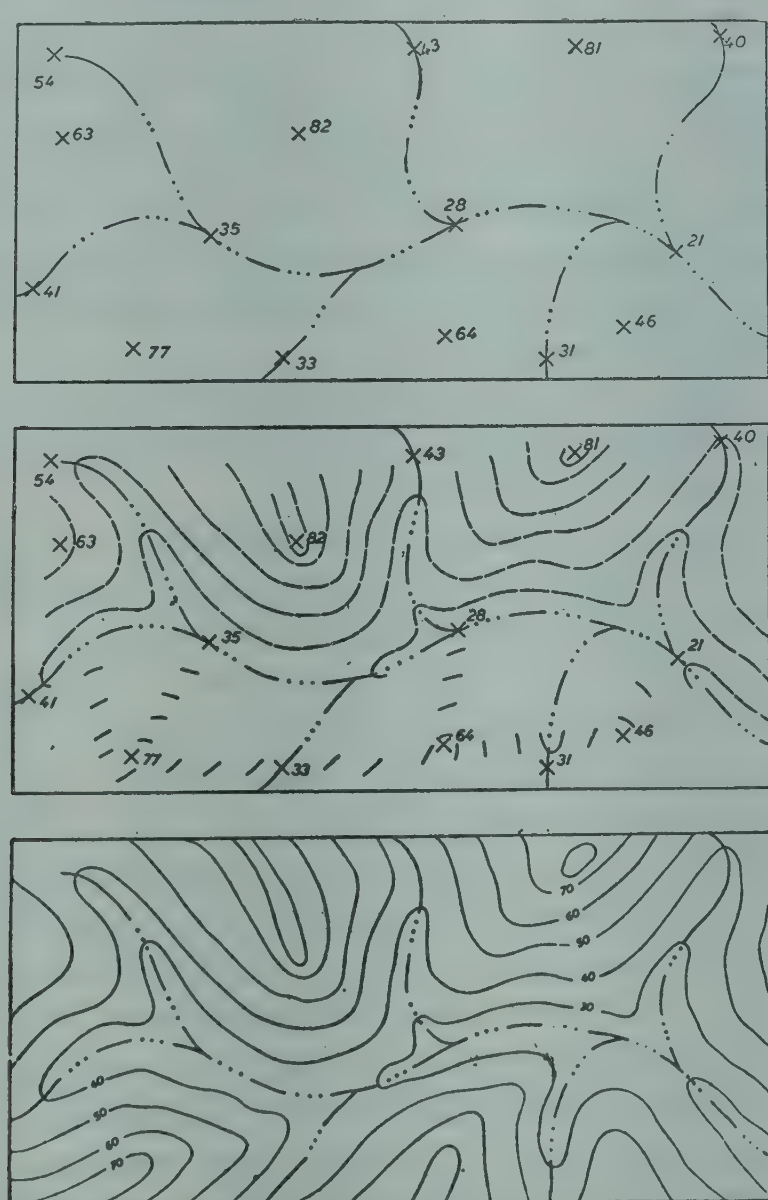


Figure 145 : Three stages of contour interpolation.

The selection of the sample points for the measurement of elevation complicates the drawing of contour lines. Eelevations of these points do not coincide with the values of contour lines everywhere. The contours are placed at proportionate distances from the known points as shown in figure 145. This amounts to saying that they do not always represent real elevations.

There is another type of error that enters into contouring. The selection of points for which measurements are made, is not done on any scientific basis. Statistical geography suggests that for a given size of the 'universe', there is some lowest limit of the number of samples which must be taken to make the samples representative of the universe. This principle of statistics has not yet been applied to topographical surveying and contouring. We do not know the ideal number of points to be selected for measurement, given the degree of slope and the amount of relief.

The arbitrarily selected points for which we have elevation data are called control points. Each control point has its x, y and z axes values. Error in any of these three values will undermine the accuracy of a map. The desired accuracy is further undermined by the fact that contour values do not always conform to the values derived for the control points as illustrated in figure 145.

Contours are only indicative of slopes and many other terrain details. Some of their charcteristics are given below :

1. They are horizontal to the dip of the land and perpendicular to the direction in which the surface water runs ;
2. They are closed lines ;
3. Steeper the slope, closer the contour ;
4. They bend up-stream while crossing a river, and
5. They do not show up minor relief features.

Interpolation of contours : By interpolation of contours we mean the drawing of contour lines in a map by estimating the points in between various spot heights through which a particular contour will pass. A river course and number of spot heights are given in figure 145. Our problem is to draw cotours at an interval of 10 feet. If the minimum height given is 21, we should find out the spots with 30,40,60,70 ft. and so on. If there are several points having 30 ft elevations, they should be joined to give 30 ft contour. But in case, for example, there is no point having 30 feet elevation, we have to draw the contour by interpolating 30 feet contour between points having higher and lower values. Suppose two such points have 28 and 43 ft elevations. The 30 ft contour has to pass through a point lying in between these two points. Actual location of the point wlll be two-fifteenth of the distance between 28 and 43 feet point from the first point. We can determine the other points also in the same way.

Representation of slopes by contours :

The distances between successive contours as measured on planimetric maps indicate the nature of the slope. Contours are made at regular intervals but they do not appear equi-distant when viewed vertically. They come close together when slopes are steeper. As the slope gradients flatten, the distances between the contours increase. Thus the spacing of contours at equal intervals enable us to get a generalized impression of the nature of terrain (Figure 146).

Slopes are of three types :

1. Uniform slopes,
2. Concave slopes, and
3. Convex slopes.

These are shown by contours and slope profiles in figure 147.

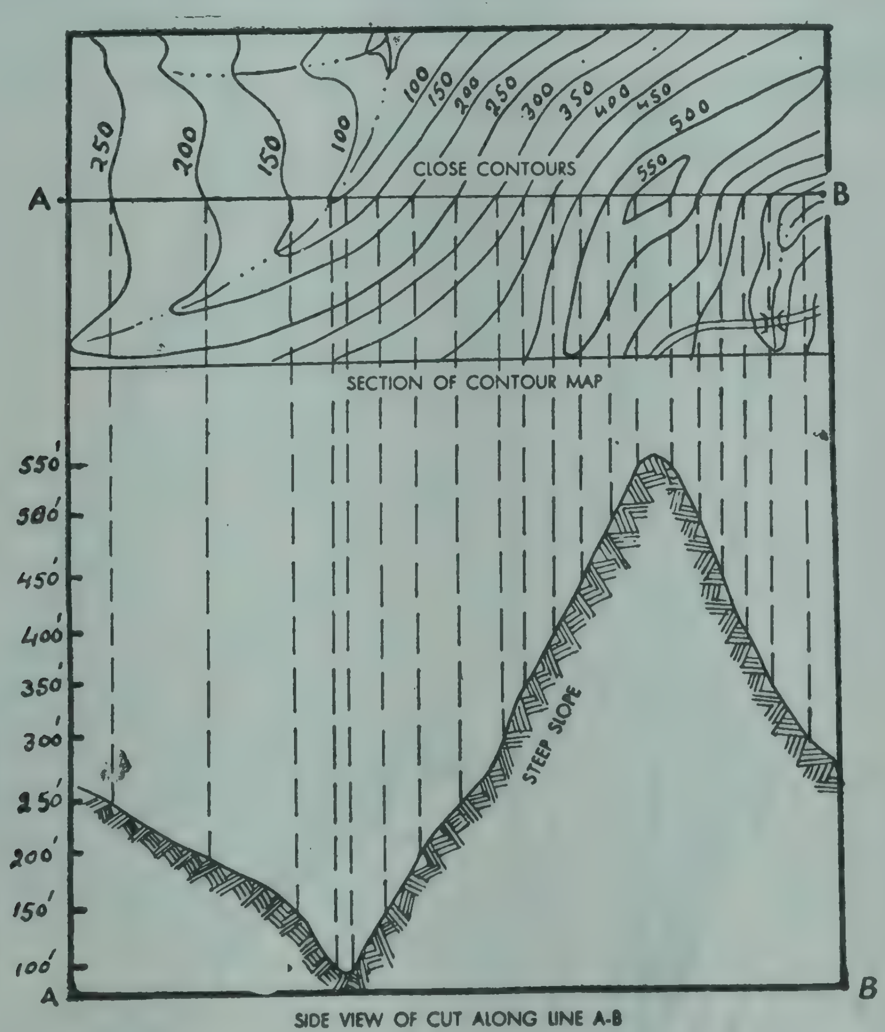


Figure 146 : (a) Relation between the slope and the contour intervals

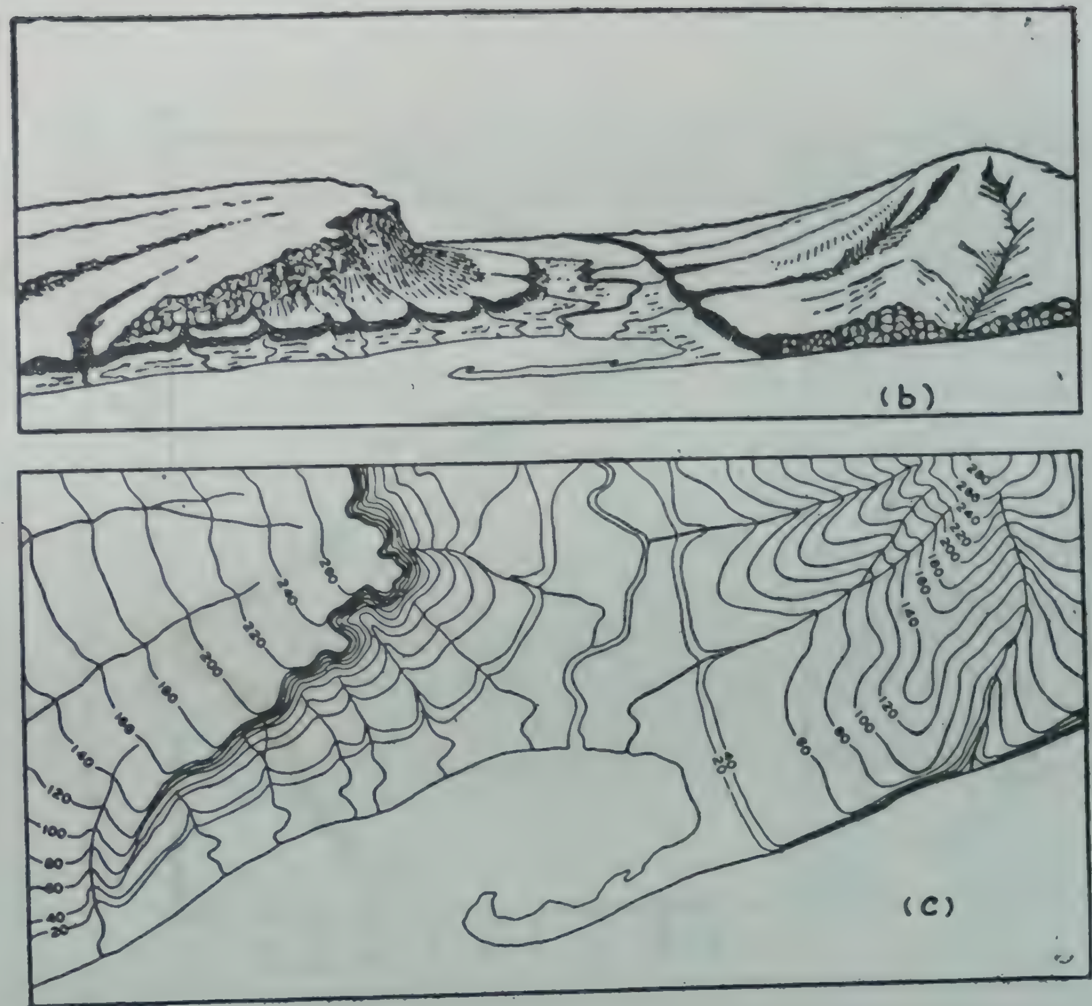


Figure 146 : (b) a sketch of landscape, and
(c) a contour map of the same area

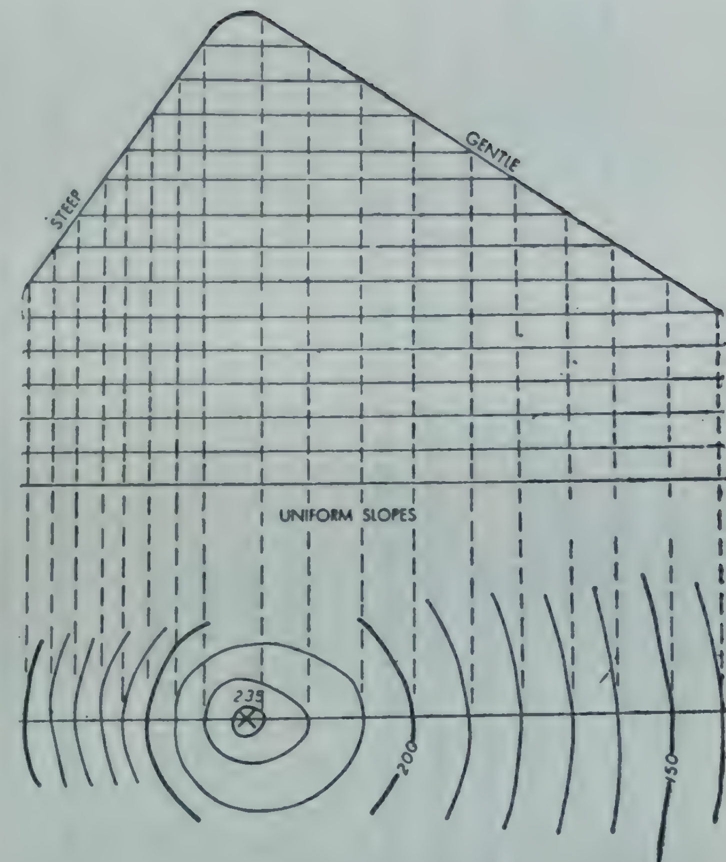
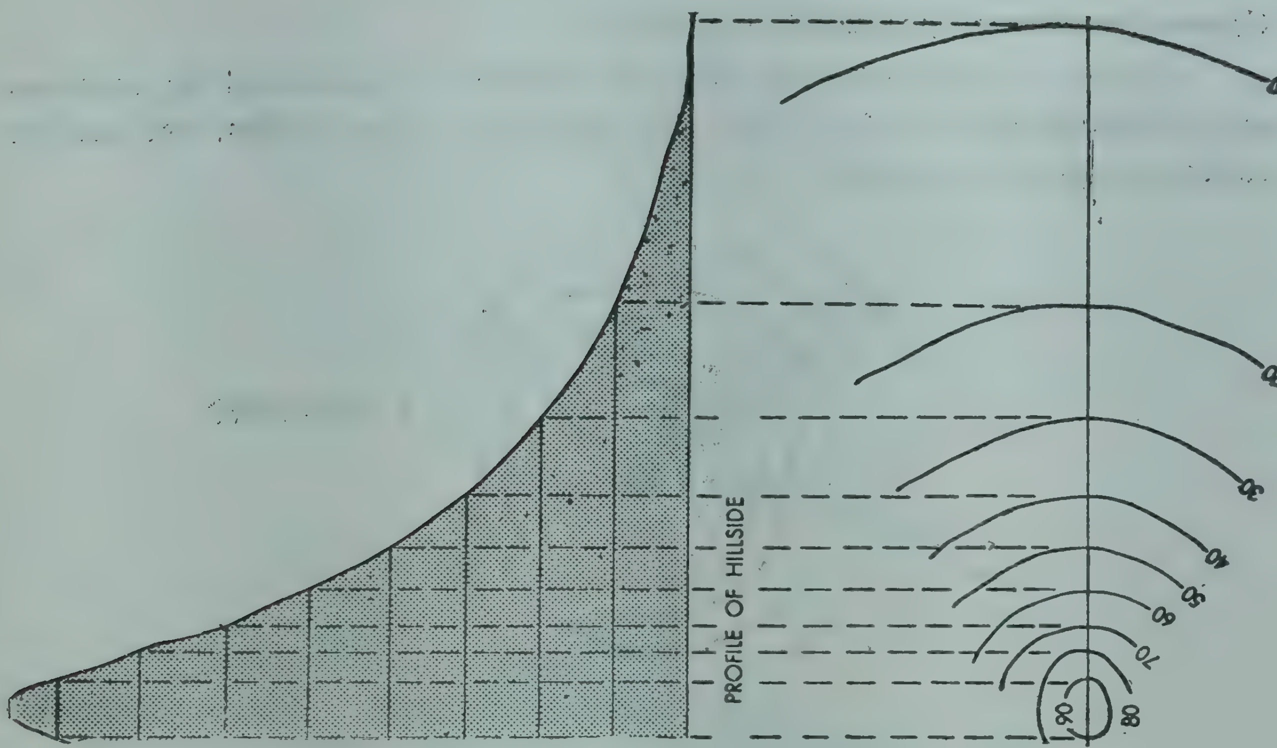


Figure 147 : Slope representation by contours :
(a) Uniform slope



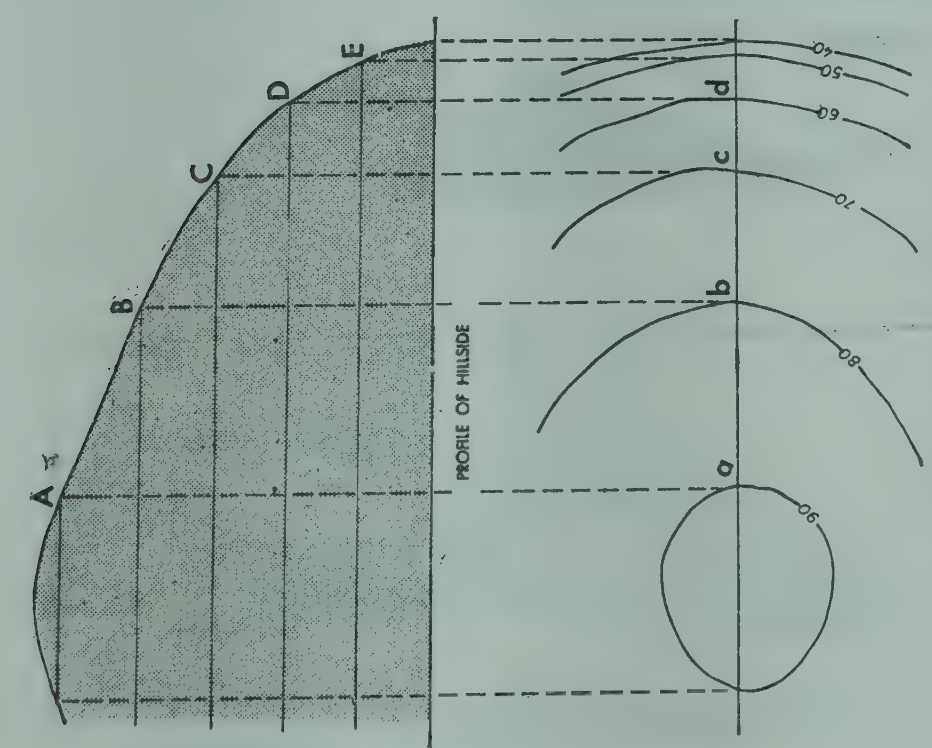


Figure 147 : Slope representation by contours :
(b) Concave slope (c) Convex slope
(From Map Intelligence)

Common landforms represented by contours ;

Example of some of the common landforms represented by contours and profiles are given in figure 148. For drawing a slope profiles, see section under profiles in this chapter.

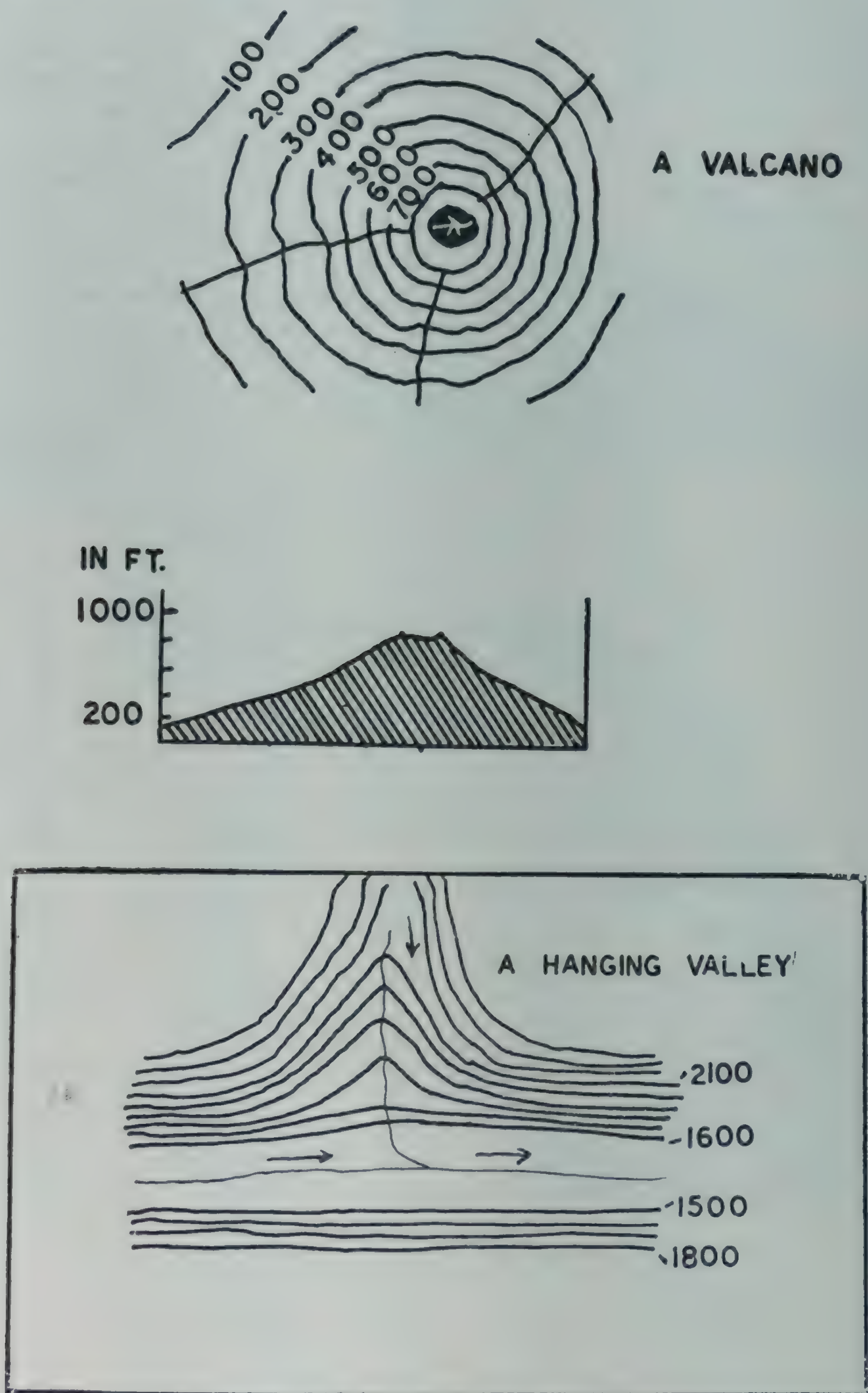


Figure 148 : Common landforms represented by contours.

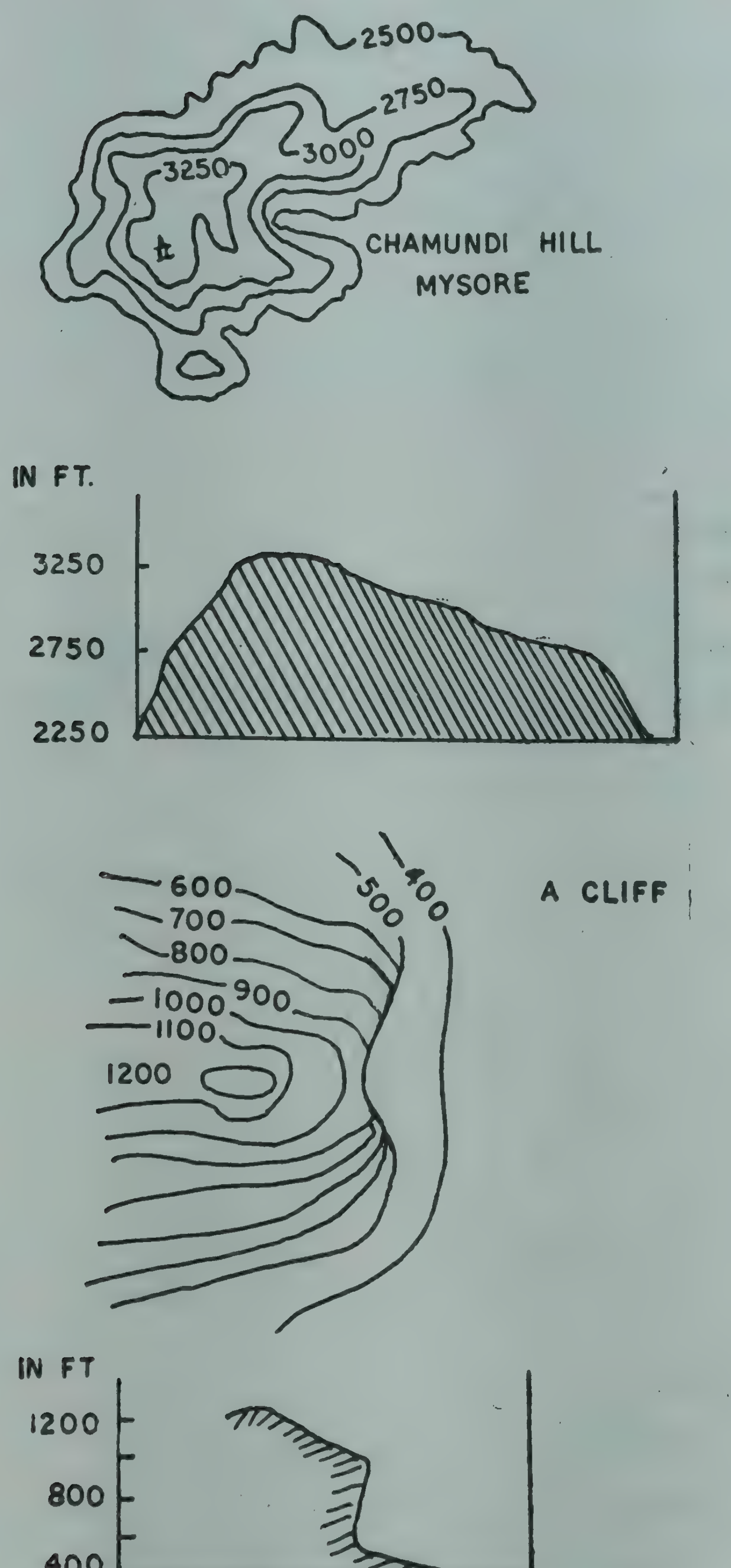


Figure 148: Common landforms represented by contours.

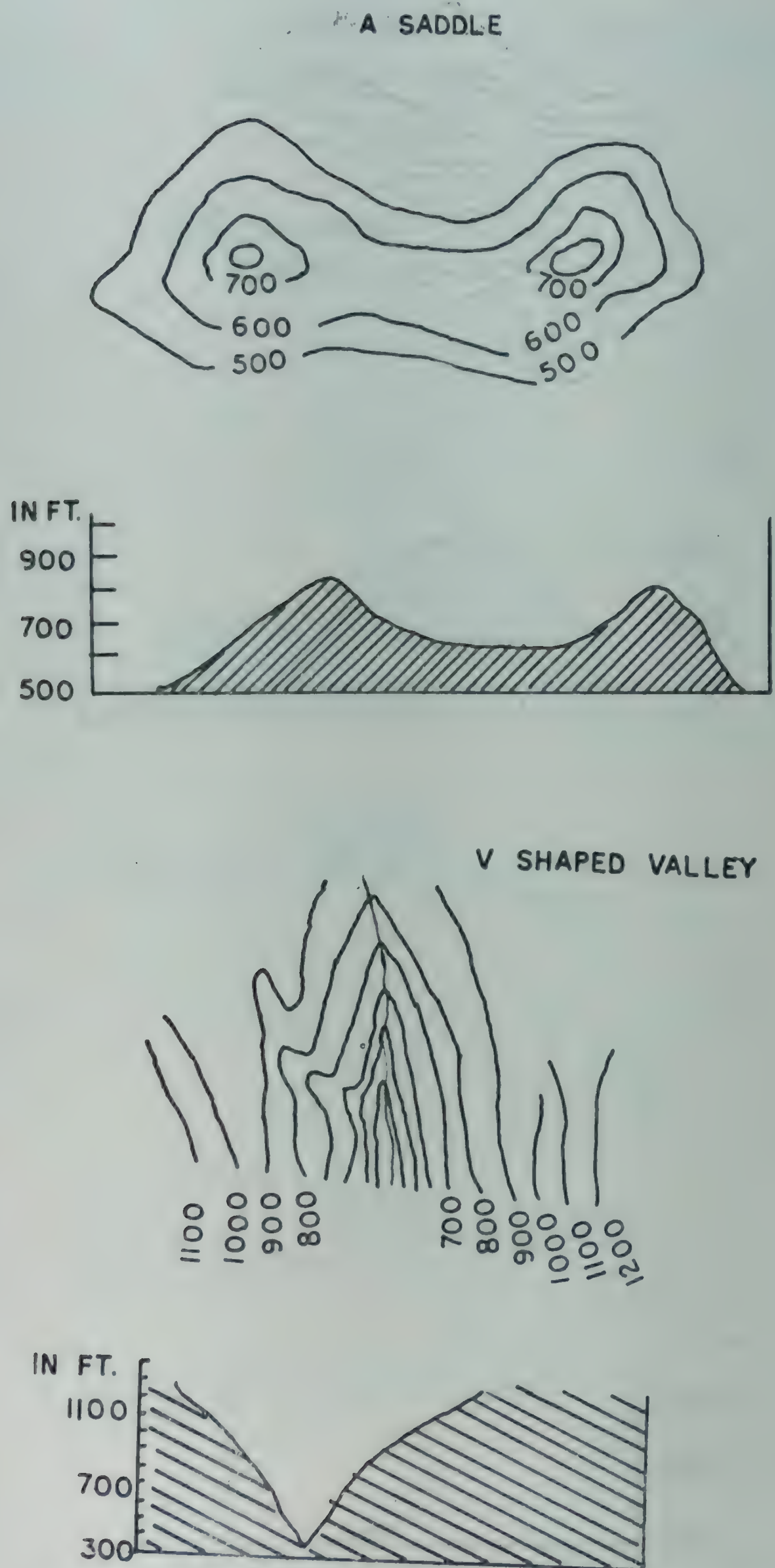


Figure 148 : Common landforms represented by contours.

INTERVISIBILITY

In military opearations, and explorations, it is often necessary to determine intervisibility between two given points on a contour map. There are two methods available to us. The first method consists of drawing of a slope profile. If a straight line joining the two points on the slope profile is not cut by an intervening relief feature, the points will be intervisible (Figure 149). This is called the *graphical method.* The other method is based on the calculation of gradient. To determine the intervisibility select the highest point C in between A and B. Calculate the gradient of B from A, and then of C from A. If the gradient of AC is higher than that of AB, A and B are not intervisible; but if the gradient of AB is more than that of AC, the two points are intervisible.

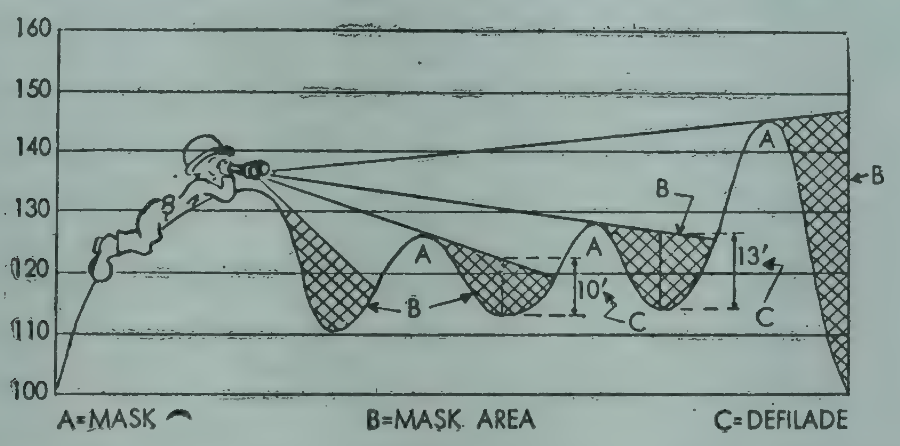


Figure 149: Determination of Intervisibility. (From Map Intelligence)

PLASTIC SHADING

Contours are an effective means of portraying terrain but they suffer from a very serious perceptual limitation. They fail to give the third dimension visually. Plastic Shading is a technique which, when used in conjunction with contours, goes a long way in removing this deficiency.

In its simplest form, shading is a technique of representing relief as viewed from a horizontally lighted relief model. If we photograph a relief model illuminated from one side, we will get a picture which will be similar to that of a shaded picture. Usually, light is supposed to be focussed from the north-west. The south-eastern slopes appear to be relatively darker. For the same reason, the south-western and north-eastern slopes appear gray (between white and black). The principles underlying plastic shading are illustrated in figure 150. The shading of a contour map is done with the help of an air-brush or carbon pencil or charcoal or crayon, the slopes are shaded according to the principles stated above. When

completed, a shaded map, unlike a contour map, gives a continuous gradation from white to black. This means, that while printing the map, the terrain plate will need half toning (see chapter on map reproduction).

Figure 1‘0. Plastic Shading

The usefulness of shading as a technique of representing relief is beyond any doubt. It gives a very useful relief background for many of the thematic maps showing cultural data. The population maps of the National Atlas of India (English edition) have effectively used the shaded relief to indicate the relationship between relief and population distribution. This cannot be done, if contours or hachurs had to be used. Contours and hachurs clutter the map and make its reading difficult.

TANAKA KITIRO'S METHOD

This technique was developed by Prof. Tanaka Kitiro of Japan in 1931. It transforms a contour map into a kind of profile shading. First of all a contour map is ruled with closely set horizontal lines, as in figure 151.

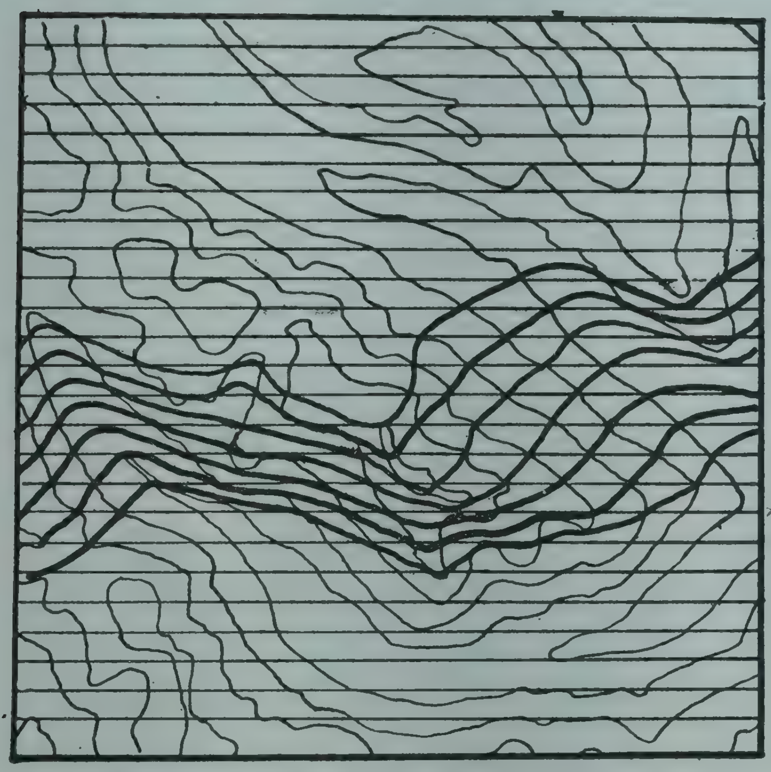


Figure 151: Principles underlying Tanaka method of relief representation

Beginning with the intersection of a horizontal line with the lowest contour, successive intersections with next higher horizontal line and higher contour line are joined by a line. This process is continued until one gets to the highest contour. Thereafter, the intersections of the successive horizontal lines and contours downwards are joined together. The resulting wavy lines appear to be profiles produced by an inclined plane (Figure 152).

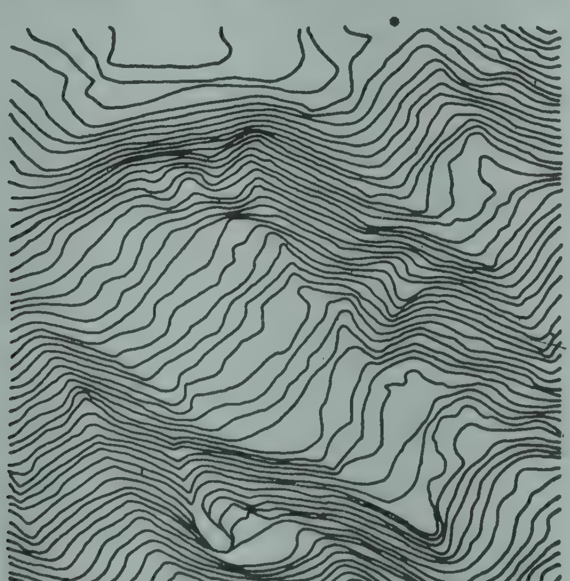


Figure 152: An example of relief representation by Tanaka method.

In 1950, Tanaka devised the technique of illuminated contours. On a gray background, the contours on the north-western side of the slope are shown white whereas on the south-eastern slope black. The lines are thick but thin out at and near the junctions of the white and black contours (Figure 153). Robinson and Thrower, later in 1957, devised another version of this method which according to them is simpler to use and more effective visually.

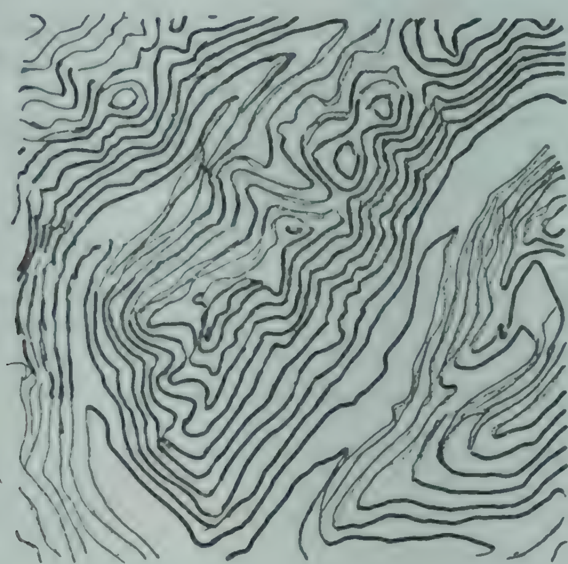


Figure 153 : Illuminated contours drawn against white background. (A modified version of Tanaka method)

LAYER SHADING OR TINTING

To show up the distribution of relatively high and low areas, areas lying in between successive contours are shaded. This technique is very useful in depicting landforms like plains, plateau etc. It is, therefore, useful for areas having varied relief. This technique, however, misleads the amateur map readers because a single colour between any two contours gives the impression of evenness of surface relief.

There are two methods of layer shading: line shading and colour shading. In colour shading either different shades of a single colour or different colours are used. Contour interval at which the colours change has to be selected very carefully. Layer tinting on small scale maps portrays little about the land surface except the elevation zones. But on larger scale maps, it represents the terrain more effectively. (Figure 154).

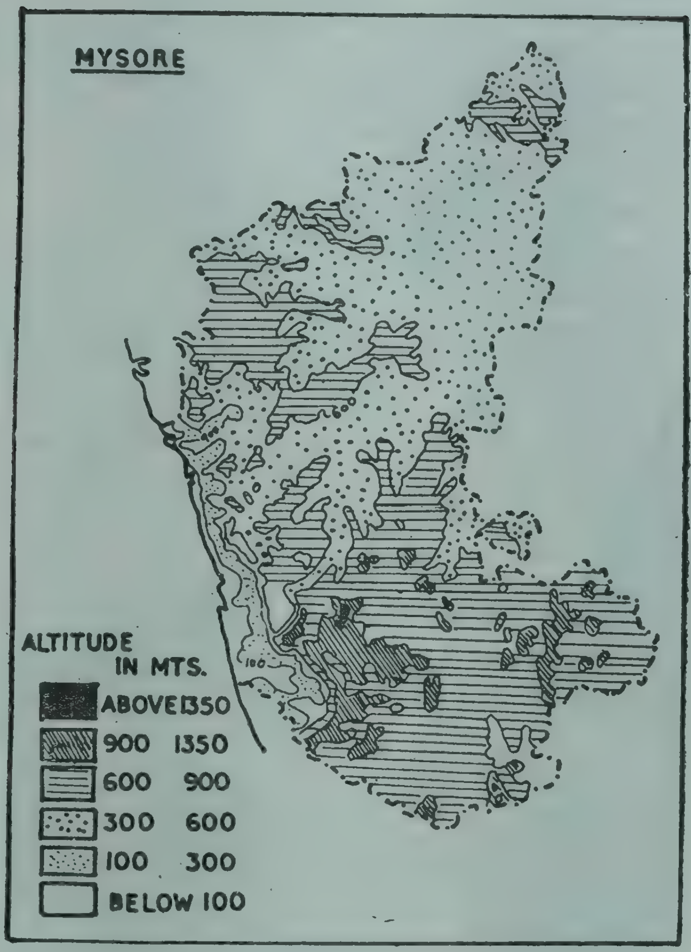


Figure 154 : Layer Shading

MORPHOGRAPHIC METHOD

This is a pictorial method of representing relief. It involves a systematic application of a standardised set of conventional pictorial symbols for various relief features. The features so represented are viewed obliquely from the air at an angle of about 45°. Late Prof. E. Raisz has been pioneer in the development of this method. The advantages of this method are quite apparent. It brings out the outstanding relief features and yet is pictorial so that even a beginner can appreciate the relief depicted on a map. It is an effective method of teaching landform geography. (Figure 155)

TERRAIN TYPE MAPS

If the objective is to indicate broad and generalized landform types, the land can be divided into various categories such as : (1) High Mountains, (2) Mountains, (3) High upland and plateau, (4) Plain, (5) Ice covered areas, etc. Each of these categories can be line shaded or stippled to produce a

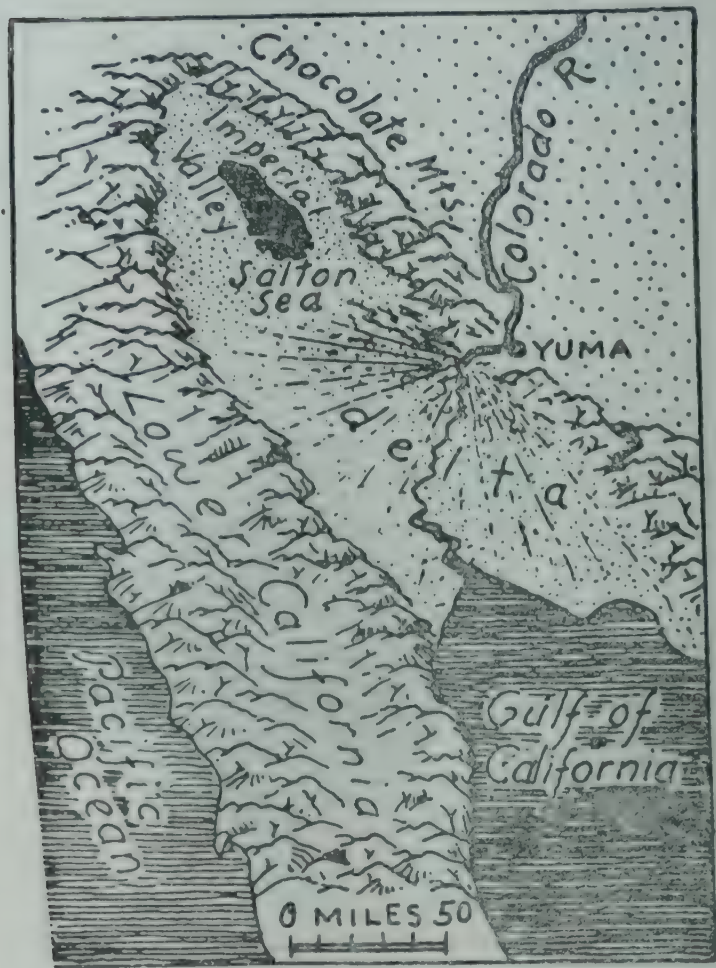


Figure 155 : Morphographic method of relief representation

Figure 156 : Terrain type map of Romania

terrain type map. We often encounter a simple four-fold classification of landforms into plains, plateaus, hills, and mountains. This can be fruitfully shown on small scale maps. It is similar to layer shading except that it gives importance to terrain type rather than to contour lines (Figure 156).

RELATIVE RELIEF MAPS

To prepare a relative relief map, the differences between the highest and the lowest elevations within a limited map area have to be determined first. To start with, a topographical sheet is divided into squares of say 5 minutes of longitude and latitude. Differences between the highest and the lowest points within each of the squares are marked and plotted on a small-scale base map. Isarithmic lines are then drawn by joining places of same difference to get a choropleth map showing relative relief (Figure 157).

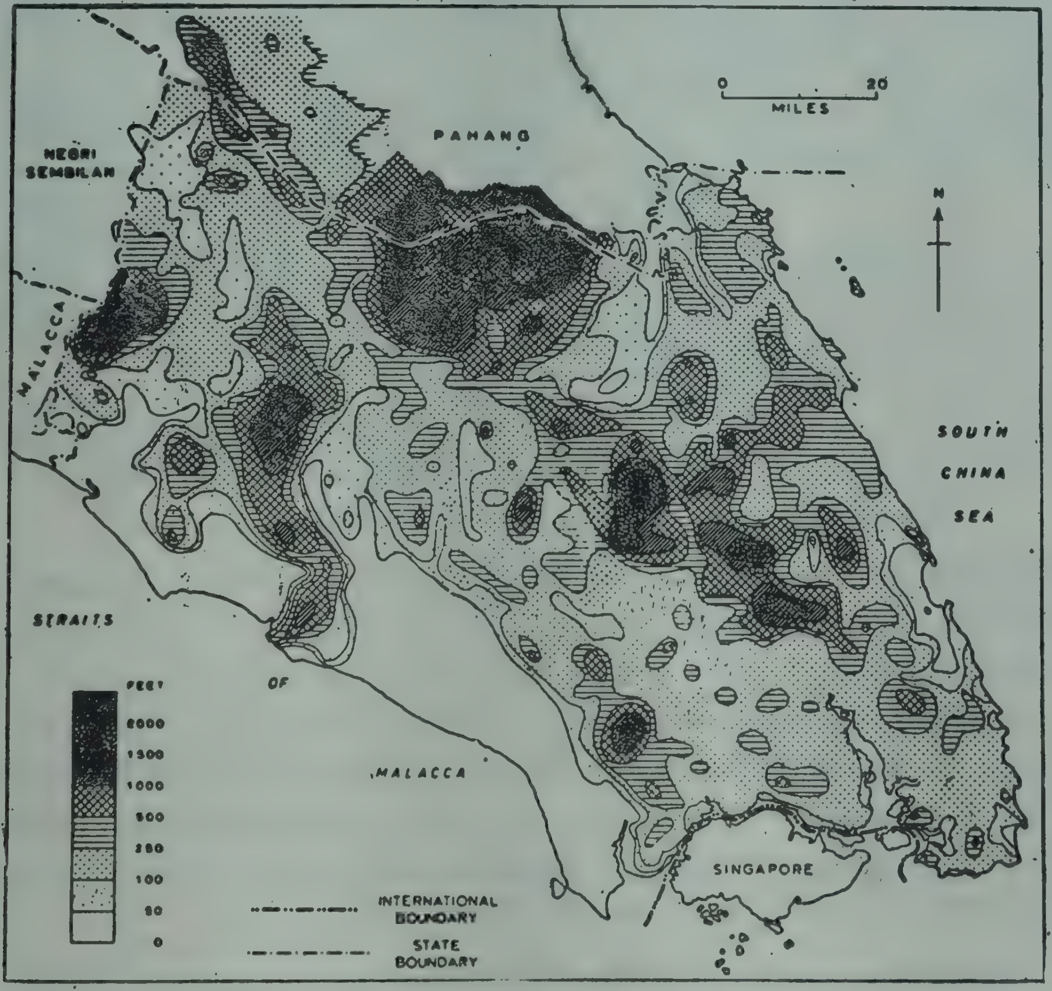


Figure 157 : Relative Relief Map of Johor State of Malaya

This technique is quite effective in depicting relief of maturely dissected plateaus, and plains with horizontal rock structures. It is less suited to geologically complex regions. It is also not very suitable for differentiating

minute yet important terrain details as they are often too small to extend beyond the confines of the squares chosen for determining the relative relief.

SLOPE VALUE MAPS

Hachuring and shading provide graphic representation of slope on medium and large-scale maps. The question of representing actual slope values on small-scale maps is not easily resolved. The technique suggested by Raisz and Henry solves this problem at least partly. It outlines and depicts slope by area symbols in a dasymetric way. The relationships between slope and important minor topographic features are well presented; the representation of major topographic features is, however, poor. In this respect it is somewhat opposite to the relative relief map.

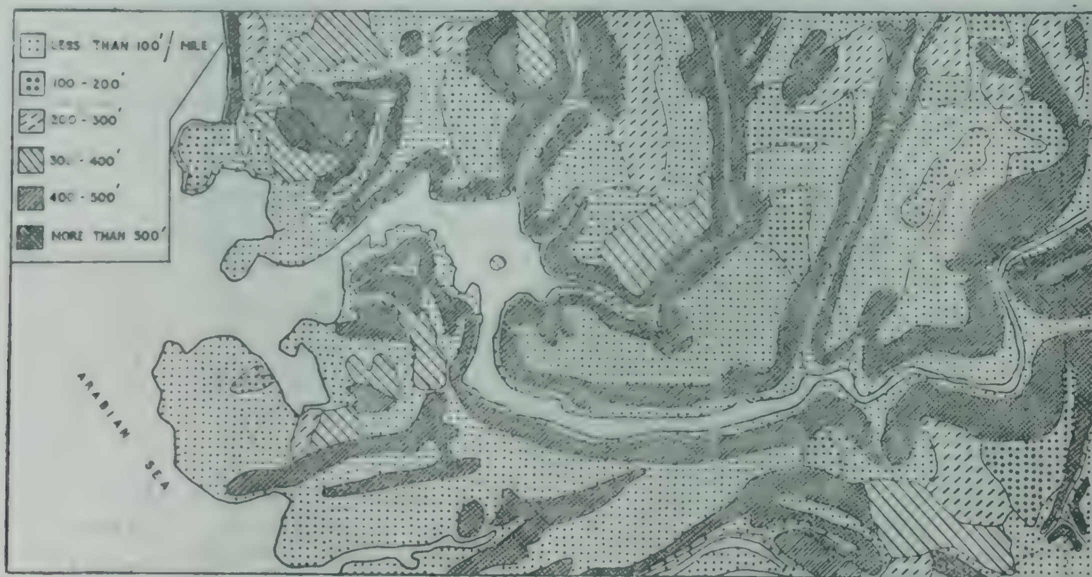


Figure 158 : Slope value map of a part of west coast, India

Operational procedure for this technique is as follows. A topographical map is divided into small areas, within each of which the contours have the same standard spacing i.e. the same number of contour-lines per mile of horizontal equivalent. A horizontal scale showing standard contour spacing is drawn from which the slope categories are ascertained by careful inspection. The chosen slope categories may be, under 50 ft., 50 to 100 ft. per mile, and so on. These categories are demarcated on large-scale maps. Later the boundaries are transferred on a small-scale map. (Figure 158).

DOT METHOD

Attempts have been made to represent slope by dots. Higher the slope, denser the dots. For the construction of such a map, a contour map is divided into squares. Average slope is determined for each of the squares. Dots are then put in each square in proportion to the degree of slope.

PROFILES

Profiles drawn with the help of a contour map often prove to be of great help in visualizing the relief. Drawing of profiles is relatively easy. The contour maps offer the base material for cross-profile drawing.

The first step in the drawing of a cross-profile is to lay a strip of paper on the line along which the profile is to be drawn. All the contour intersections, spot-heights, rivers, summits and other defined points are marked on the paper. A base line equal to the line along which profile is to be made is drawn separately. Two vertical lines are drawn at both ends of the base-line. Taking into account the relative relief of the area, a vertical scale is marked off and lines parallel to the base line are drawn at selected intervals. The vertical scale is usually larger than the horizontal scale to make undulations along the profile stand out. The relation between horizontal and vertical scales is known as vertical exaggeration. The ratio of vertical exaggeration should invariably be noted below the profile. Starting from the base line, transfer the contour intersections marked on the edge of the paper on respective lines. The lowest contour should be marked on the base line. When all the points are plotted, join them by a smooth line (Figure 159a).

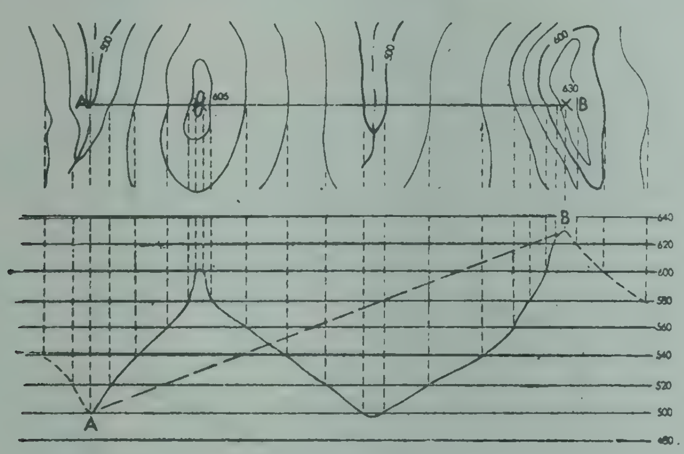


Figure 159a : Method of drawing a cross-section profiles

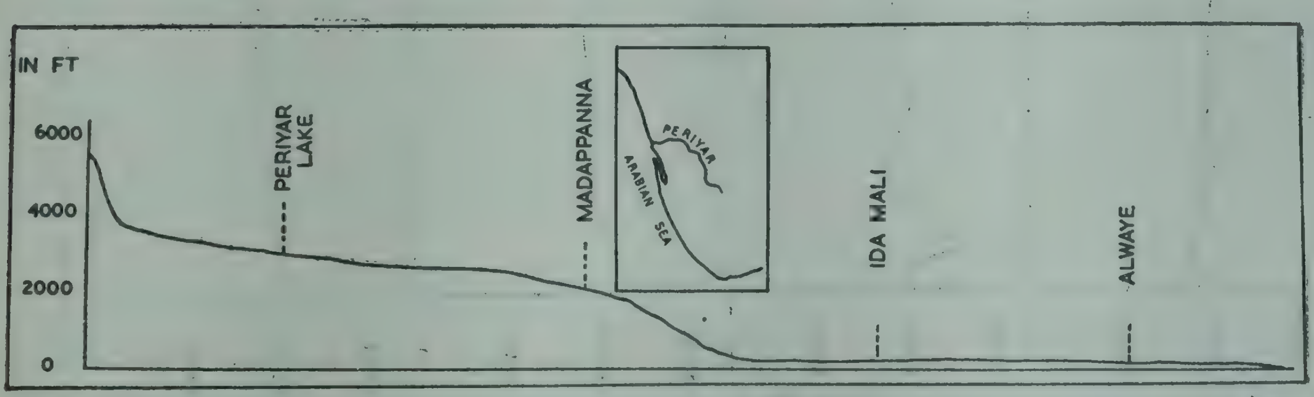


Figure 159b : Longitudinal profile

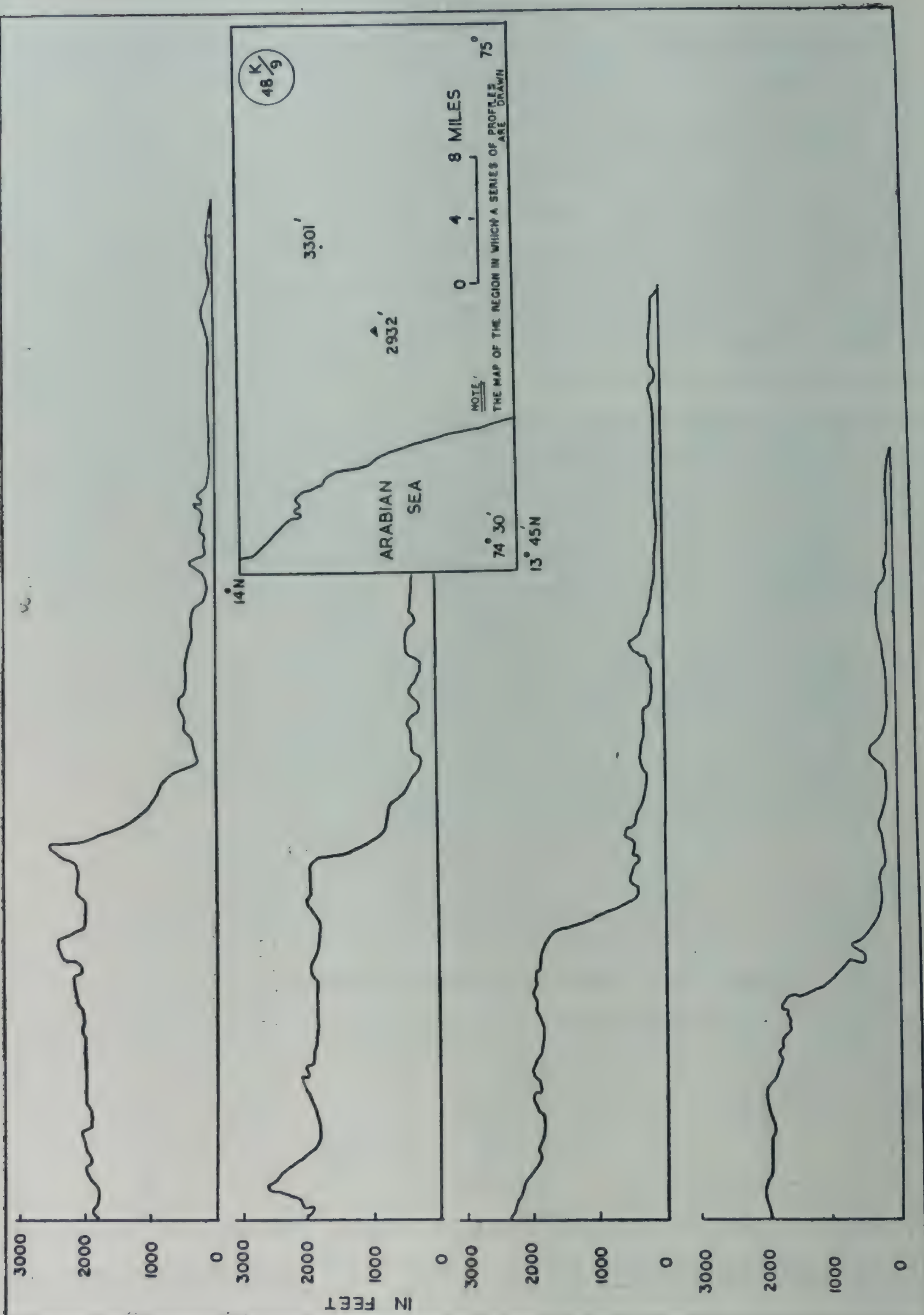


Figure 159c: Serial profiles

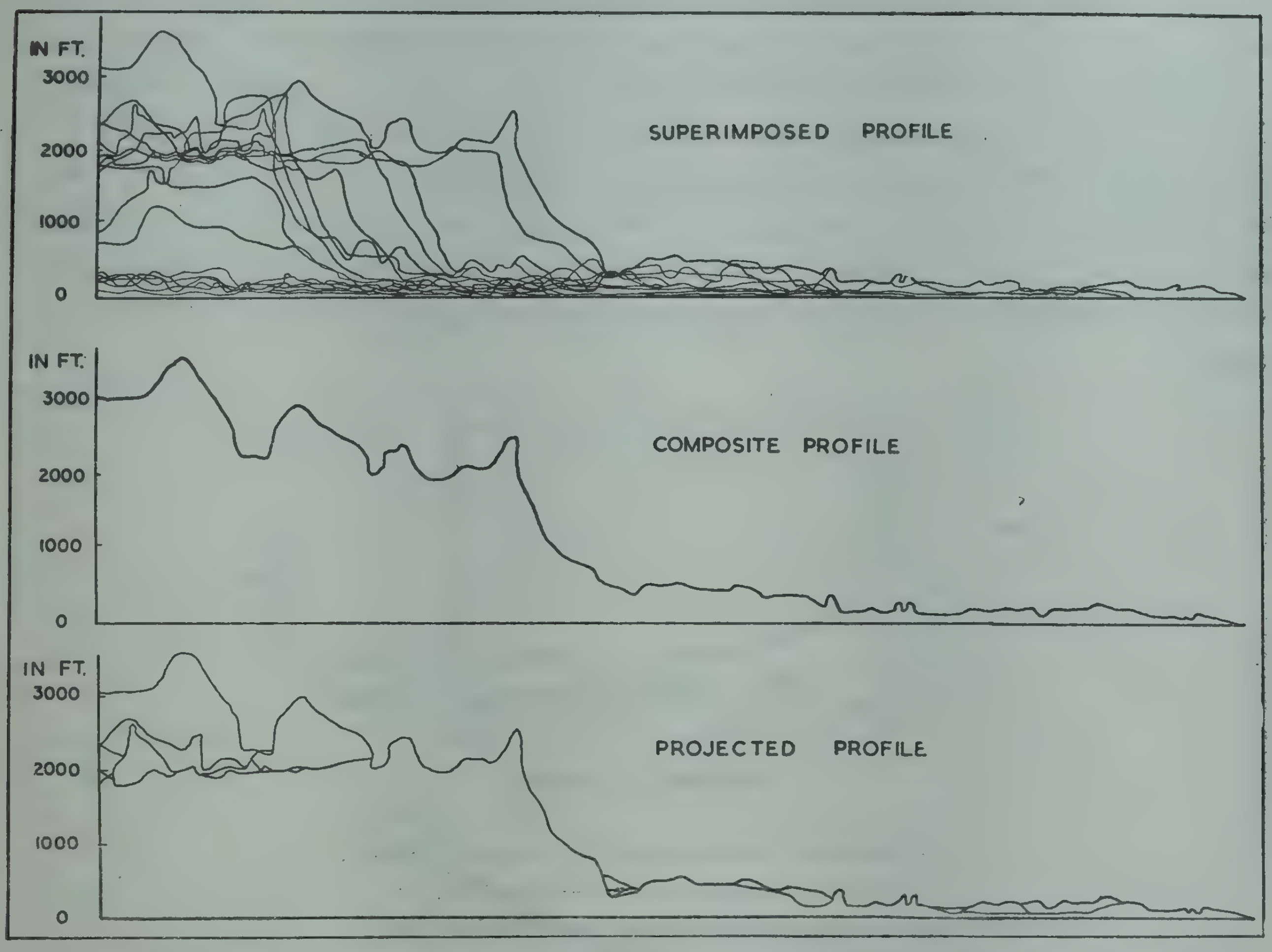


Figure 159d : Superimposed profile ; Composite profile ; and Projected profile

When a profile is drawn along the stretch of a road, or a river, we call it a longitudinal profile (Figure 159b). When cross profiles are drawn along a series of lines and are put together, we call them serial profiles. (Figure 159c) When several profiles drawn along parallel lines are put within one frame, we get a *superimposed profile*. When the highest parts of a series of profiles are shown to represent the relief as viewed in the horizantal plane of the summit-levels from an infinite distance, we call it a *composite profile*. If we remove those parts of the profiles from a superimposed profile which show the relief hidden behind higher elevations, we get a, *projected profile*. A projected profile gives a panoramic view with a distant sky-line, a middle-ground and a fore-ground. (Figure 159d)

RELIEF INDICATION BY CURVES

Hypsometric curve :

Hypsometric curve indicates the proportion of surface area at various elevations. The procedure for constructing a hypsometric curve is as

follows. Select a convenient horizontal scale to represent the area in square miles. Putting zero on the left, construct a vertical scale on the left side of the base line to represent elevation above sea level at suitable intervals. Calculate the area enclosed within different contours (0′ and 1000′ ; 1000′ and 2000′. etc.). Plot each area against its corresponding contour interval with origin indicating the total area. Join the points so marked with a smooth curve (Figure 160a). Hypsometric curve is useful for indicating relief of an island. Percentage, in stead of absolute, area can also be used in making this curve.

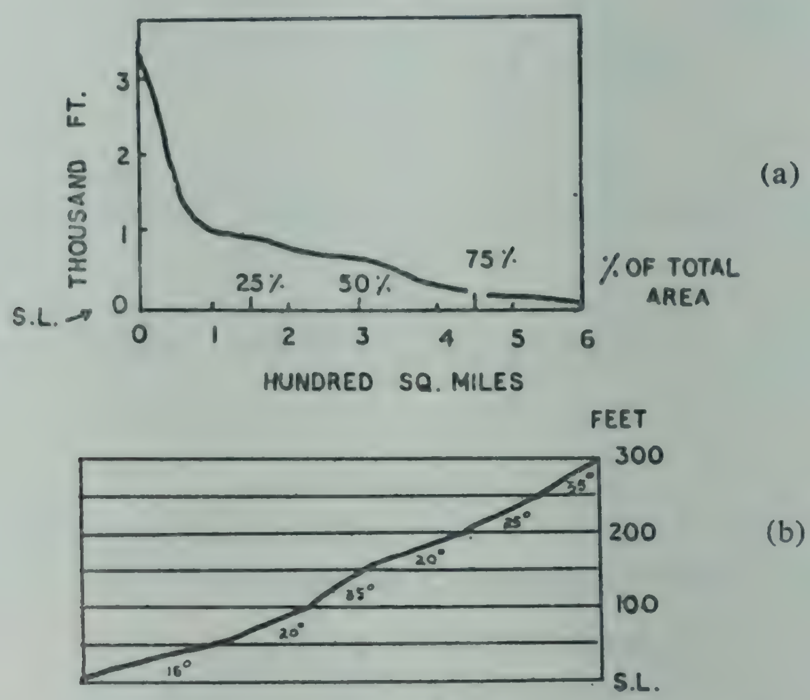


Figure 160 : (a) Hypsometric, and (b) Clinographic curves.

Clinographic curve :

It illustrates the average gradient between successive contours and shows up prominently any abrupt change in the general relief depicted on a map. To construct this curve, first of all the area of land enclosed by sea level contour should be calculated. Then the area between sea level and the next higher (say 100′) contour should be calculated. This process is repeated until areas between all successive pairs of contours are found out. Presuming that the areas so calculated are enclosed within circles, we determine the radii of these circles by using the formula $2\pi r^2$ (where r = radius). The radii can be converted by scale factor into inches. If a triangle ABC is drawn with B = 90°, CB = radius of the circle and AB = height (contour interval), the angle ACB which is the angle of slope can be calculated, using the tangent formula

i.e. $\tan \theta = \frac{AB}{BC} = \frac{h}{r}$. We can calculate the angle of slope between each succeeding pair of contours. These data can then be used to prepare a clinographic curve as shown in figure 160b.

Another curve which is useful in geomorphological analysis is the *altimetric frequency graph.* It shows the frequency of occurrence of heights above sea level (Figure 161).

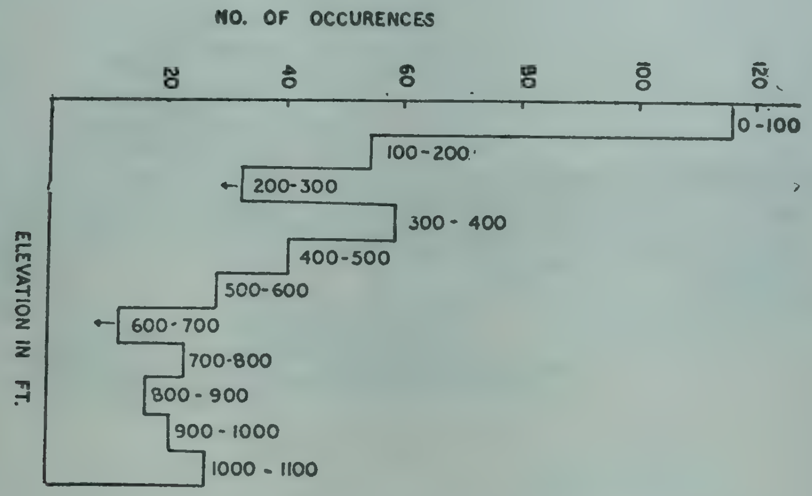


Figure 161: Altimetrie frequency graph.

FIELD SKETCHING

Field sketching is a technique of making perspective sketches of prominent features of landscape as observed from a specific point. A pencil, an erazer, a scale, a compass and a drawing sheet or sketch book are the necessary tools and materials for field sketching. It requires relatively little artistic ability, for a few ' rules of thumb ' can be used in its construction.

The first step in the drawing of a field sketch is to decide how much of the landscape to include in it. The maximum that can be included is the portion which can be seen while looking at its central point. Usually, part of the horizon is also included. A central point is selected and a vertical line passing through this point is drawn. Next step is to draw a line formed by the horizon or the level of a distant lake or a communication line. The third step consists of selection of some prominent features and the measurement of their distances from the centre with an inch scale held at an arms length. Locate these points at their respective places on the paper. For greater exactness, cut a hole in a piece of cardboard of the size of the desired sketch. Cover this hole with a piece of celluloid with grid rules. Hold it at a fixed distance from the eye and transfer the details seen, square by square on the paper. To see that the

landscape does not give an impression of being flat, the vertical scale should be exaggerated by 1.5 to 2.5 times, depending on the relative relief of the area sketched.

After the framework of the sketch is ready, the minor details can be filled by observation. Some of these details can be shown in their true shape but many others may have to be symbolized. Names of prominent features like hills, peaks, villages, etc. can also be added later (Figure 162).

Figure 162 : A field sketch.

BLOCK DIAGRAMS

Block diagrams are only too often used in geological and geographical literature to need introduction. They are sketches of relief models with the added advantage of having geological sections appended to their sides. This enables the map user to correlate the landscape with the underlying geological structure. The concept behind a block diagram is that a block of the earth crust is cut out and viewed obliquely from above.

There are three main types of block diagrams : These are (1) isometric block diagrams (2) perspective block diagrams, and (3) panoramic sections.

Isometric block diagrams :

Isometric block diagrams are of two types : (1) those drawn without the help of contours, and (2) those drawn with the help of contours.

Isometric block diagrams are a sort of pseudo-perspective block diagrams. Although they appear to be perspective, they are only isometric based on simple geometrical figures. Isometric graph paper provides ready guide lines for drawing geometrical figures upon which isometric block diagrams can be built. When drawn with the help of geometrical figures like cones, pyramids, spheroids, cylinders etc. we get the isometric block-diagrams of the first type (Figure 163).

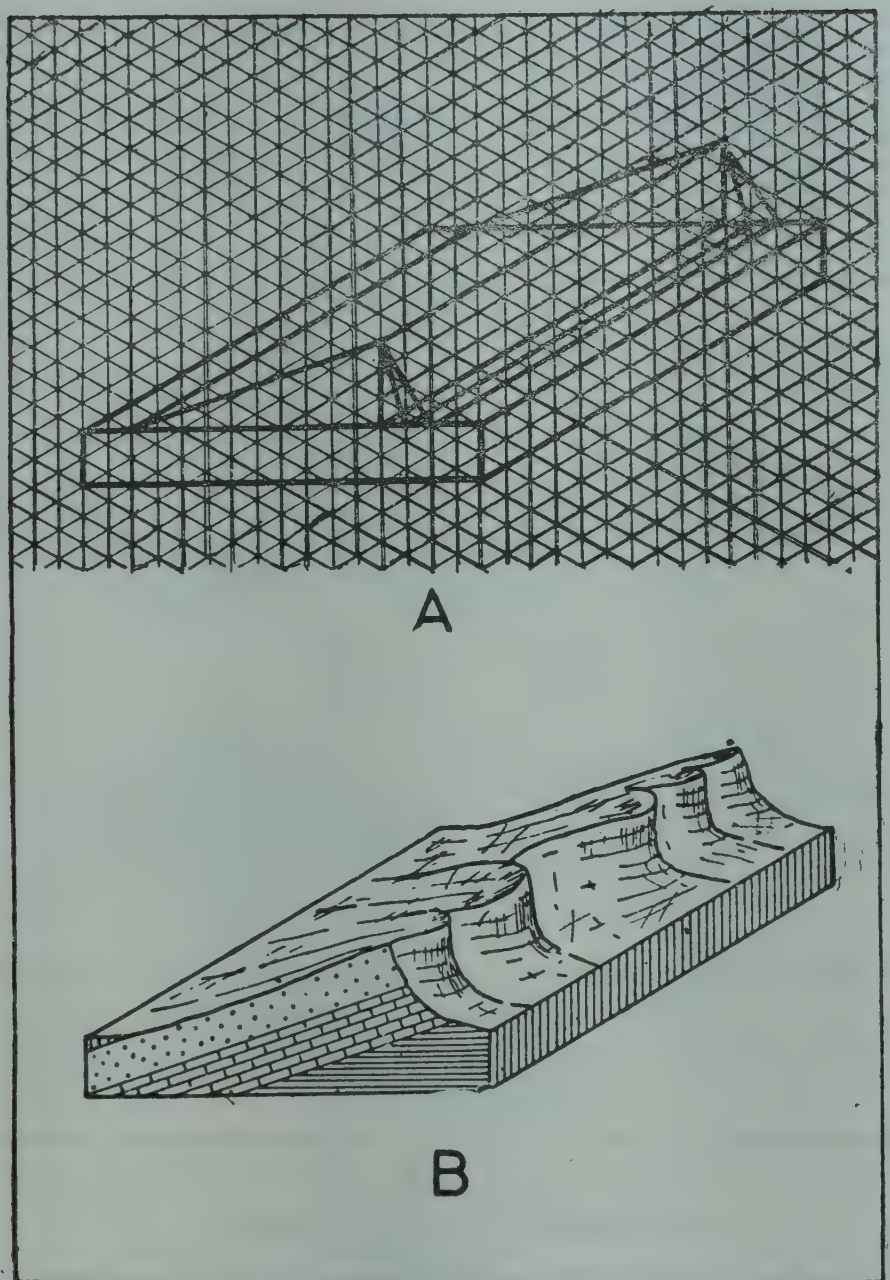


Figure 163 : Isometric block diagrams drawn with the help of geometrical figures. (Robinson)

The second type of isometric block-diagram is the one which is drawn with the help of contours. To draw scuch a diagram, trace a plan view square from a contour map. Draw horizontal and vertical lines to divide the plan into several squares. Determine the position from which the observer is looking at the plane. After deciding the orientation, project the plan with its squares into a rhombus as shown in Figure 164 B. The obliquity is determined by the angle between the base and the visible sideb. This angle should be between thirty and forty-five degrees. Transfer the relief-details from the squares to the rhombus using one of the techniques explained below.

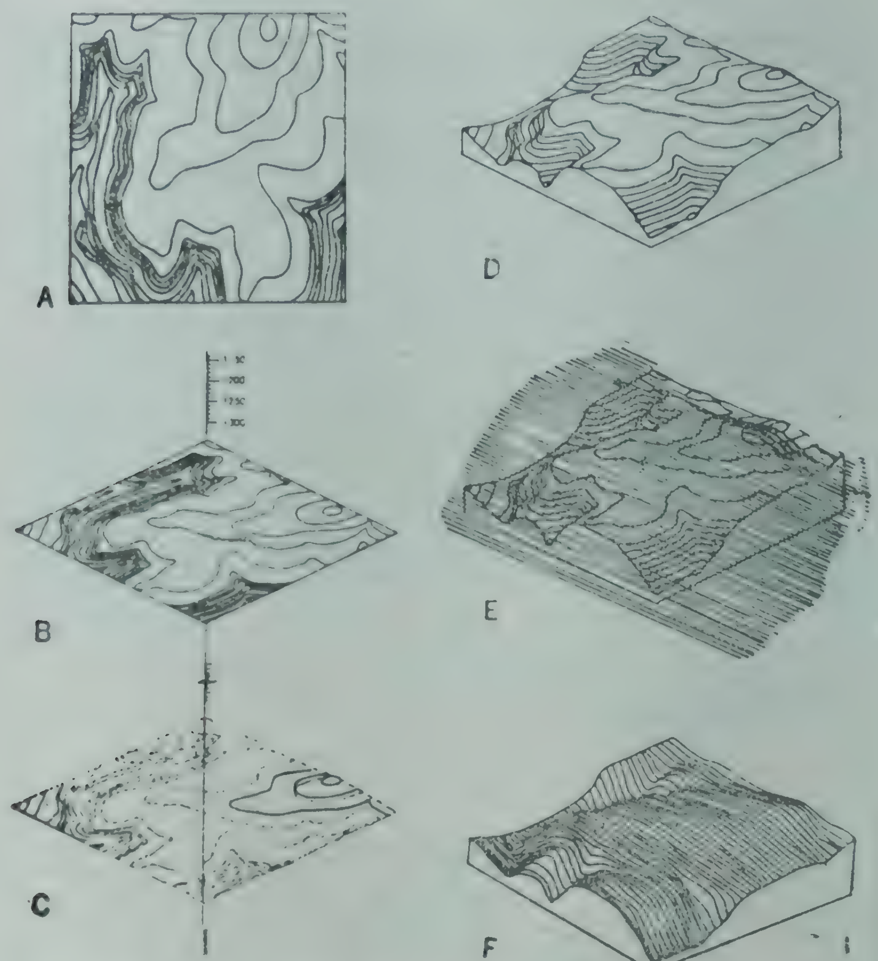


Figure 164 : Method of drawing isometric block diagram with the help of contour maps.

There are two methods of transferring relief from a square to a rhombus. (1) the multiple section method, and (2) the layer method. The first

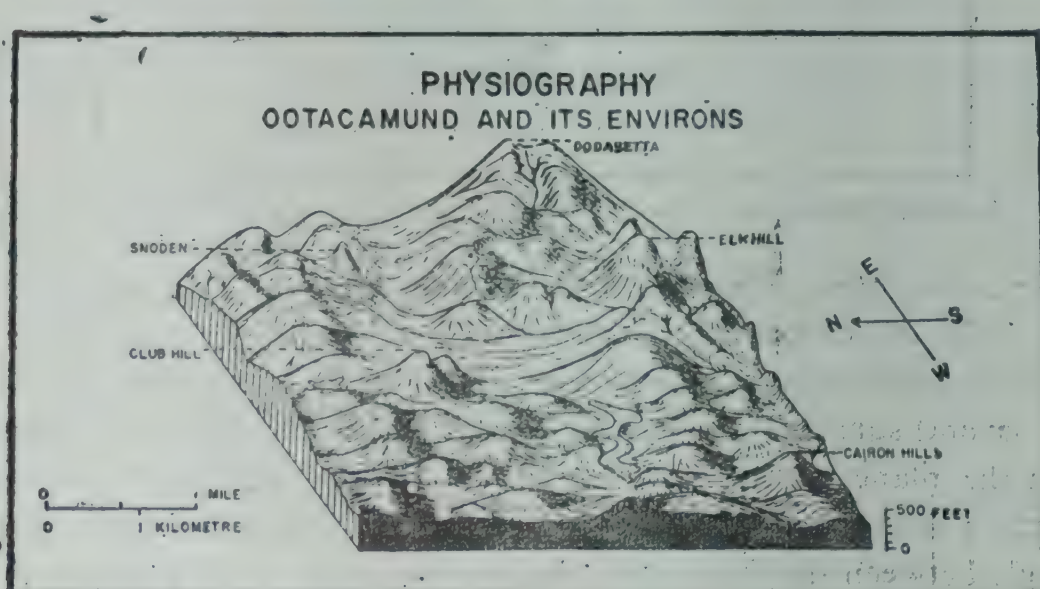


Figure 165 a : Methods of representing relief on isometric block diagrams : Multiple section profile method

method involves the drawing of section profiles along all the horizontal lines of the grid and then drawing of relief by form lines. The method as shown in Figure 165a is self explanatory. In the second method the highest contour on an overlay. To trace the next lower contour, move the overlay to the next contour interval. Repeat this process with respect to each contour. Other details are filled up subsequently. (Figures 151, 164 and 165b).

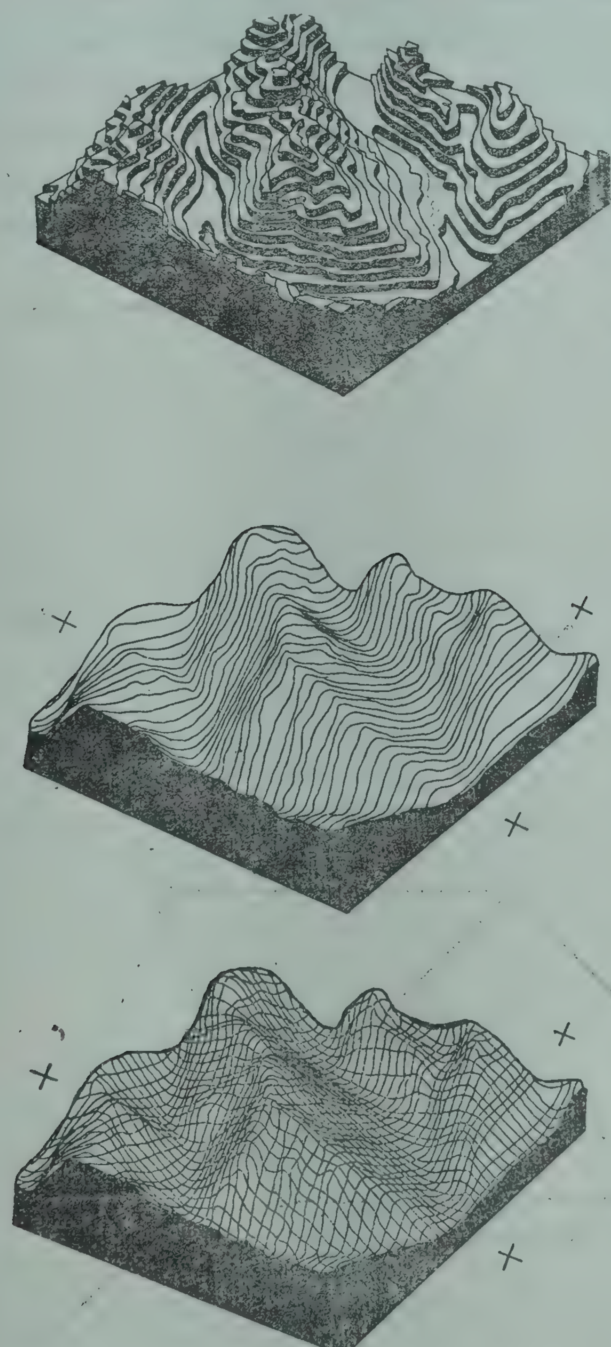


Figure 165 b : Methods of representing relief on isometric block diagrams : Layer method.

Perspective block diagrams :

In the isometric block diagrams, the vertical as well as the horizontal scales are kept uniform as the sides of the square and the rhombus are kept indentical. But such an arrangement does not give a natural appearance to the landscape. The natural appearance is the perspective appearance in which features at a distance appear shorter than their real size. The perspective effect can be given to a block diagram by making the rear-side of the block narrower than the front side and by allowing the side lines to converge somewhere on the observers horizon. The point of convergence is called the vanishing point. If only two sides of the block are made to converge at one point on the horizon, the diagram is called one-point perspective diagram. If

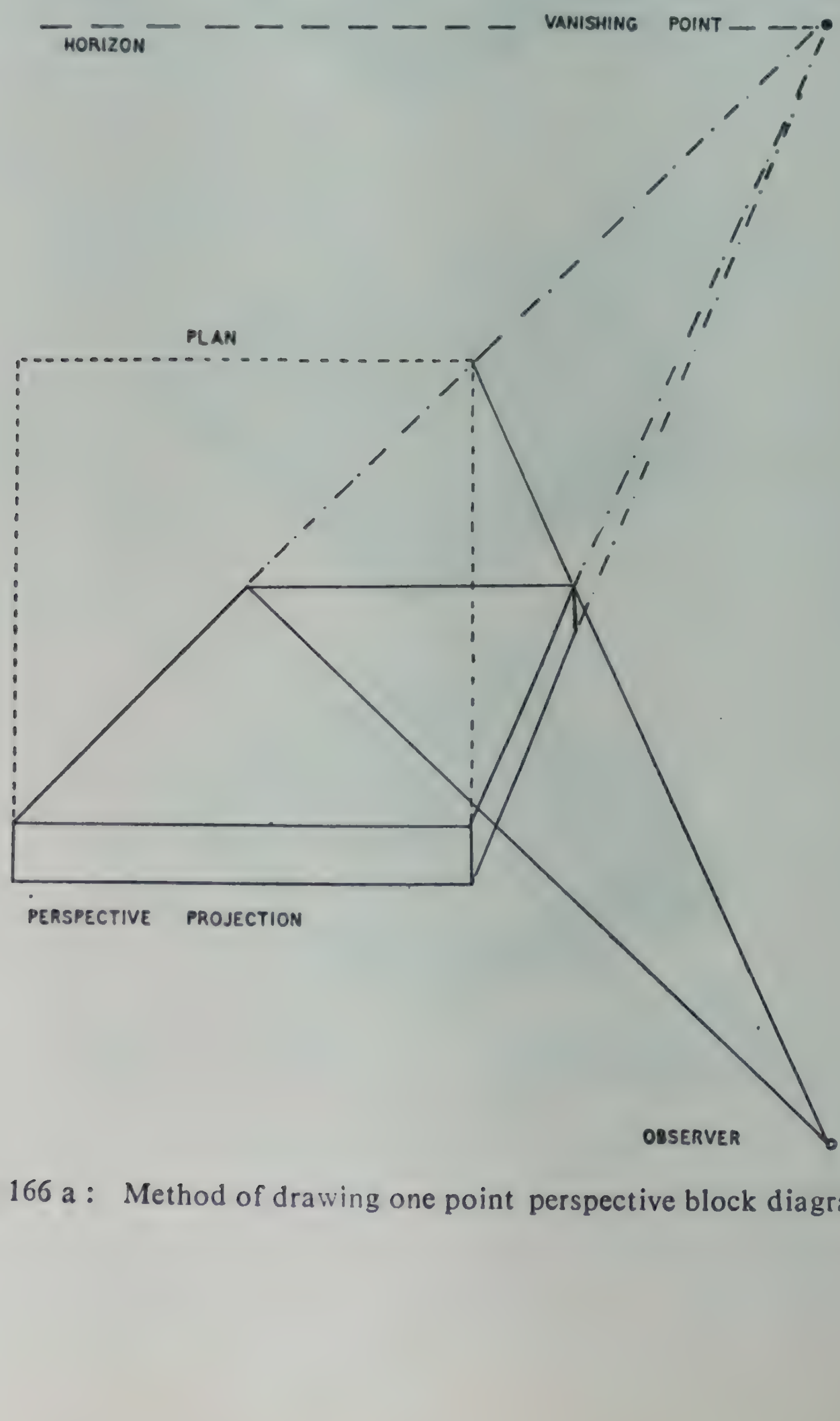


Figure 166 a : Method of drawing one point perspective block diagrams.

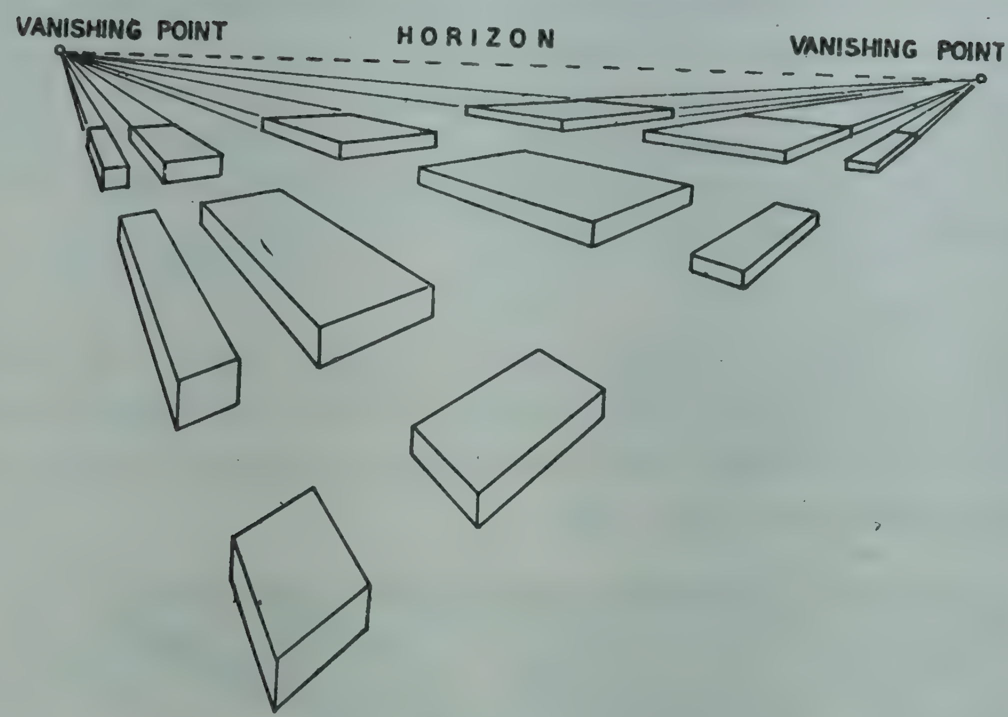


Figure 166 b : Method of drawing two point perspective block diagrams.

the remaining two sides also converge at a second point on the horizon, it becomes a two-point perspective block-diagram. The principles underlying the two types of perspective block diagrams are illustrated in Figure 166.

In one point perspective the front of the diagram is a horizontal line drawn parallel to the back edge. The sides converge towards a common point on the observers horizon. It should be noted in this regard that both the horizontal and the vertical scales change when a base plan is given a perspective appearance. The technique of drawing section profile along the sides is given in Figure 167. If structural details are not desired, the sides can be made solid black.

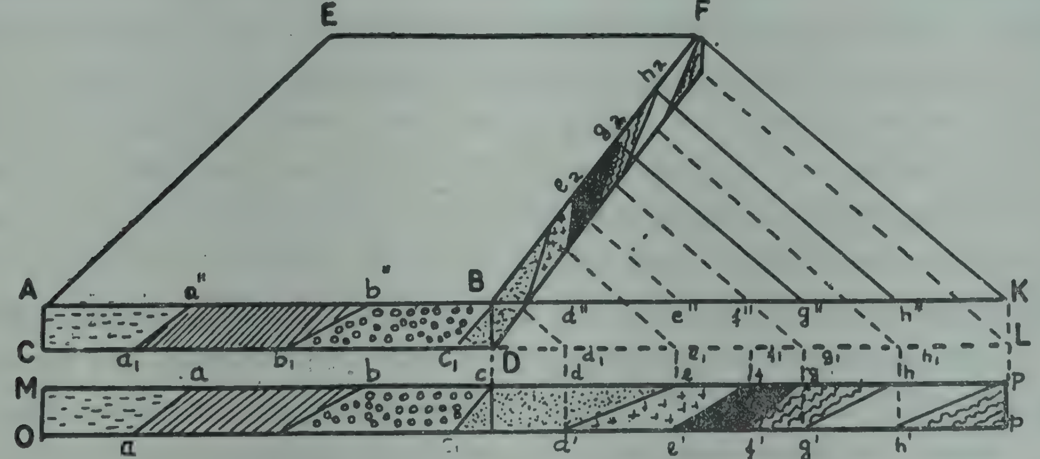


Figure 167 : Method of drawing section profiles along the sides of a block diagram.

The two-point perspective block-diagram is considered to have two vanishing point as shown in figure 166. By changing the location of the vanishing points or that of the block with respect to the vanishing points, one can develop as many perspective blocks as one desires. The method of transferring the topographical details from the map to the diagram is the same as in isometric block diagrams.

Panoramic sections :

These are elongated block diagrams showing geology in the frontal section prominently and giving the surface details in a very narrow strip at the top. These are very effective tols for explaining relationship between geology and surface topography (Figure 168).

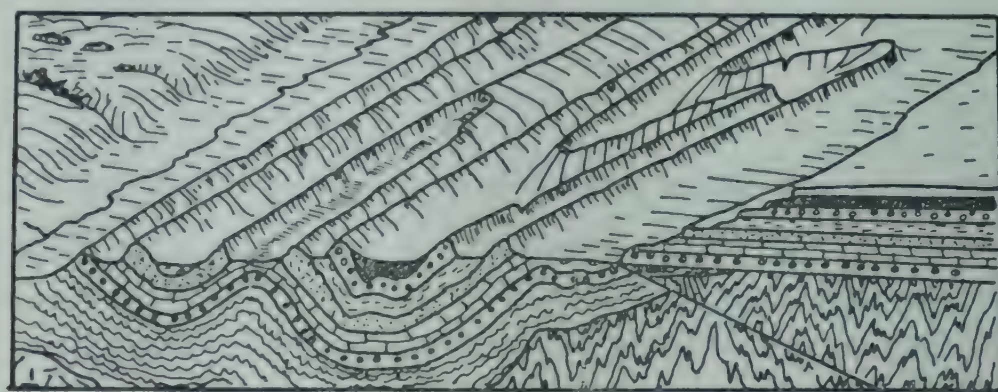


Figure 168 : A panoramic section.

MECHANICAL METHODS OF MAKING BLOCK DIAGRAMS

There are two simple mechanical devices which can be used in transforming a contour map into a block-diagram. These are (1) dufour, and (2) anamorphoser. A dufour consists of a long rod which slides along a groove. One end of the rod has a nail which fits in the groove. At the other end of the rod is fixed a nail (pointer) or a pencil. Similarly, in the middle of the rod there is arrangement for fixing a nail or pencil (Figure 169). If the diagram is to be made on a scale larger than that of the contour map, the pointer should be fixed in the middle but if it is to be made on a reduced scale, the pointer should be fixed at the end of the rod. Contour map is placed edgewise under the pointer and a sheet of paper is placed under the pencil. As the pointer is moved along the borders of the map, the pencil draws a rhomboid. To draw the contours, move the pointer along the lowest contour. Move the paper down one contour interval and draw the next higher contour. Each time, the pointer is placed on a higher contour, the paper is

moved downwards. After the contours are ready, other details are filled up manually.

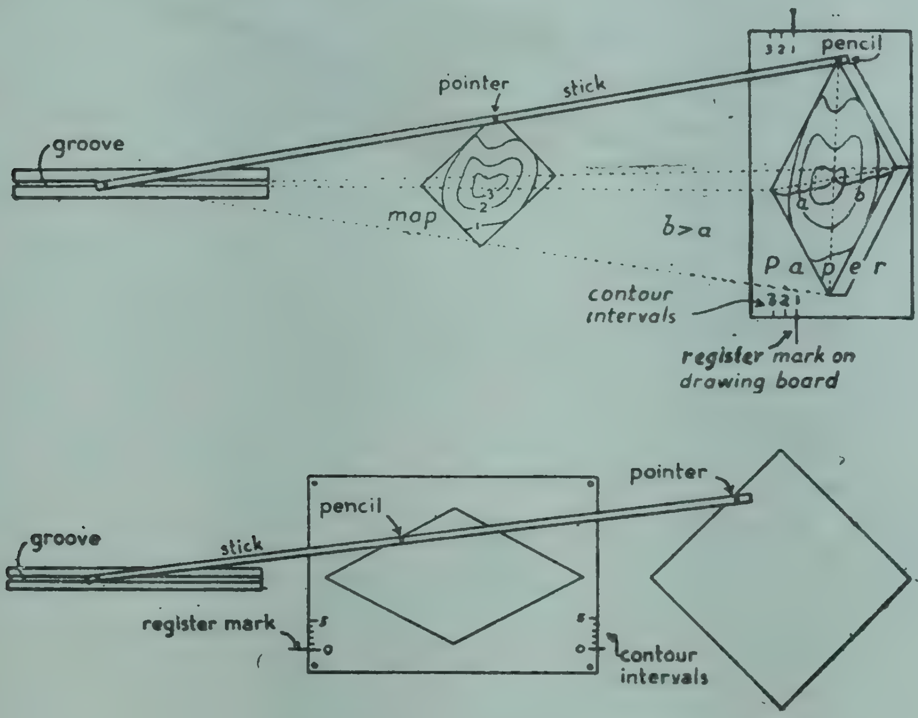


Figure 169 : A Dufour (Raize)

The other mechanism used in making block diagram is what Prof. Jenks calls anamorphoser. It is a simple optical device which transforms images passing through two slits located on parallel planes. The two slits are oriented at right angles. The rays passing through a negative enters the first slit and converge along its linear axis. Then they pass through the rear slit and tend to converge along the opposite linear axis. The amount of transformation and change in scale is controlled by three critical dimensions (1) distance separating the slits, (2) distance between the original copy and the front slit, and (3) distance between the rear slit and the photographic negative (Figure 170).

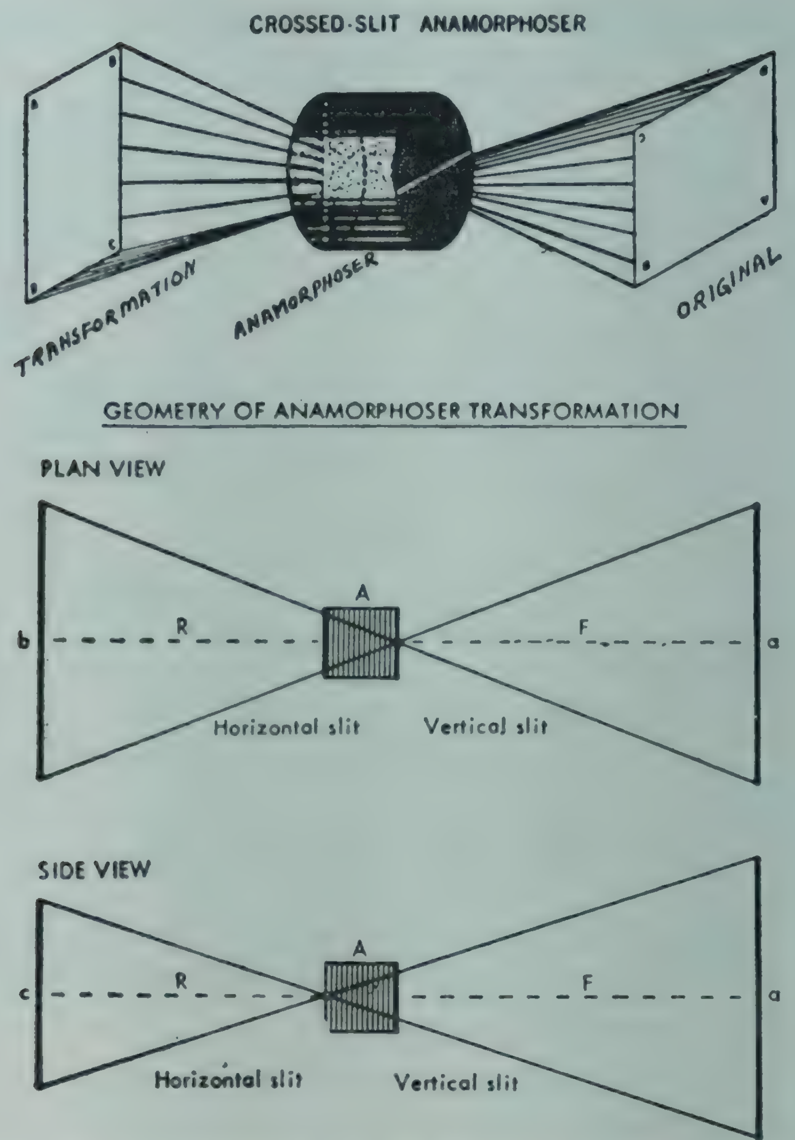


Figure 170: An Anamorphoser and the geometry of transformation (Jenks).

a = A known dimension on the original map.

b = The long dimension of the transformed map; dimension "a" multiplied by the reduction or enlargement ratio.

c = Short dimension of the transformation; dimension "b" multiplied by the foreshortening ratio which equals the sine of the angle of view.

A = Distance between slits of the anamorphoser.

F = Distance from the front slit of the anamorphoser to the original map.

R = Distance from the rear slit of the anamorphoser to the transformed copy.

Transformation Formulae

$$F = \frac{(a+c)A}{b-c} \qquad R = \frac{c\,(F+A)}{a} \qquad b = \frac{(a+c)\,A + c\,F}{F} \qquad c = \frac{a\,R}{A+F}$$

Note: The geometry of anamorphoser transformation is controlled by the relative dimensions of A, R, and F. When any one of these dimensions is altered, the scale or the shape of the transformation will change. For example, 1 : 1 ratio of a to b could be altered to 1 : 2 by changing the dimension R. Similarly, the ratio of b to c will change when either A or F is altered.

TERRAIN REPRESENTATION AND MAP FUNCTION

The techniques that we have discussed in this chapter can be used effectively only if they are selected with reference to the function of the map. Every map is a communication device. In certain cases it contains discretely selected limited information. In certain others, it contains a variety of information designed to serve the widest range of potential users. Whatever the nature and amount of data represented, the selection of symbols should be so judicious that it effectively meets the desired communication needs.

Selection of a particular terrain representation technique should be guided by following considerations.

1. Type of terrain information that the map is designed to give,
2. Aspect of the terrain to be represented,
3. Relation between terrain and other symbols,
4. Perceptual problems of the map users, and
5. Limitations of cost and reproduction processes.

If all these factors are considered carefully, the portrayal of relief will be effective and compatible with the purpose of the map.

CHAPTER XIX

MAPPING THE WEATHER AND CLIMATIC DATA

Atmospheric pressure, temperature, wind direction and velocity, humidity, evaporation, cloudiness, precipitation, snow cover, and visibility are the important elements of weather and climate. One can sub-divide each element further to get 'sub-elements'. For instance, precipitation can be classified as hail, snow and rain. In the process of observation, the above said elements can also be combined to form 'compound elements'. Equivalent temperature (temperature and water-vapor pressure), cooling power (temperature, wind velocity and humidity) and continentality (solar radiation and temperature) are some of the examples. In contrast to this, we have 'derived elements' which include ranges, frequencies, variabilities, etc.

Since a geographer is more interested in Climate, the mean values for the above said elements are of great significance to him. Mean values give the average weather i.e. climate. It does not, however, mean that we can dispense with actual measurements of daily weather conditions. The methods of representing weather and climatic data given in this chapter, therefore, deal with both the daily and mean values.

MAPPING THE WEATHER DATA

The day-to-day weather observations are used to prepare synoptic charts and a variety of other diagrams. Synoptic charts give a composite picture of the weather conditions as observed at a particular time. Synoptic means 'seen together'. Various diagrams used to explain the dynamics of weather conditions form important elements of a book on climatology.

Synoptic Charts :

There are hundreds of meteorological stations spread all over the world which observe and record weather data. Such stations are located both on

land and water. In the high seas ships function as meteorological stations. With the use of air planes and satellites for recording and photographing weather conditions, we can now say that there are meteorological stations not only on the land and the high seas but also in the air.

These weather stations prepare special reports for farmers, masters of ships and pilots of air-crafts. They also function as laboratories where the state of the atmosphere over an entire region, country, continent or ocean is put together from reports sent by hundreds of weather stations.

The data received from various weather stations are so much and detailed that they all cannot be incorporated in a single chart unless they resort to coding designed specially to give economy of expression. These codes are called meteorological symbols. When these symbols are put at their appropriate position on a base map, we call such maps, synoptic charts.

Synoptic charts provide the primary tools for weather forecasting. They permit one to locate and identify different air masses, pressure systems, fronts and areas of precipitation. When a consecutive series of charts showing weather conditions at every 3 hours or so are examined, it becomes possible to predict the future weather patterns. A synoptic station model is given in Figure 171.

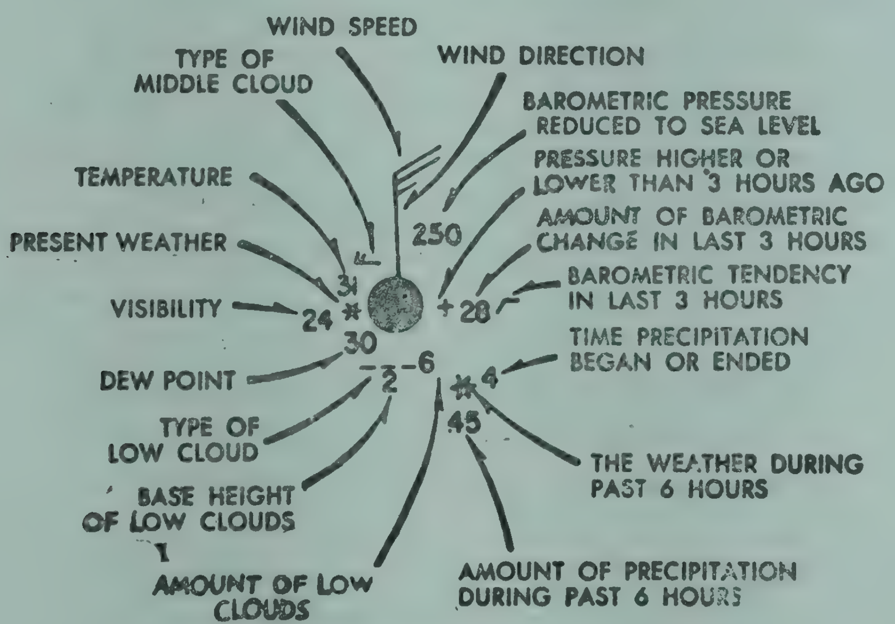
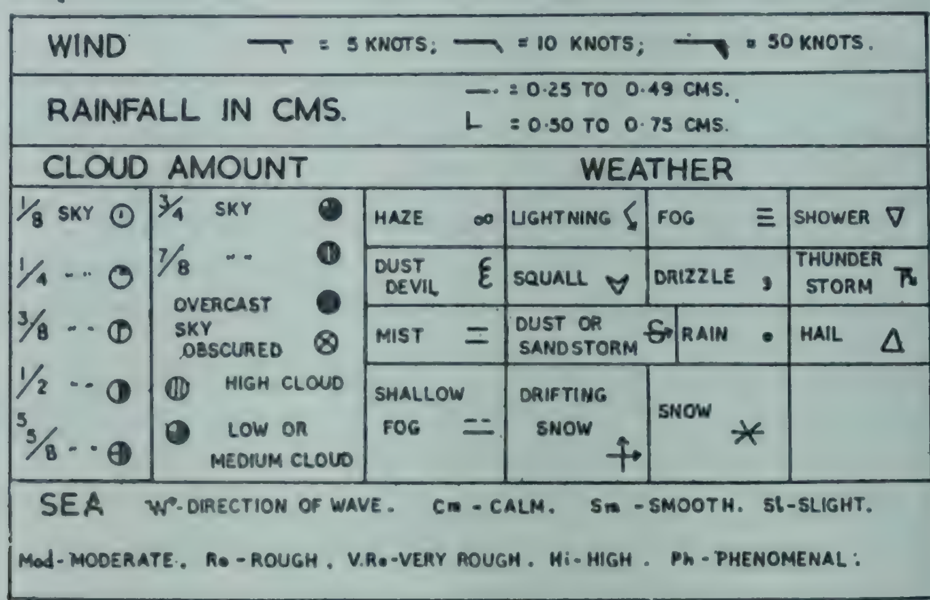


Figure 171 : Synoptic station model (Cantzlaar.)

A weather map or chart is essentially a representation of the frontal systems and the pressure systems that overlie the areas outlined in the map. Before attempting to interpret a weather map it is necessary to familiarize oneself with the meteorological shorthand or symbols. All the elements of a

weather map are represented by symbols, majority of which are now used all over the world. These symbols are given in Figure 172.



Figuce 172 : Weather symbols

Indian Weather Map :

The meteorological observation service was first started in India in 1864 with its headquarters at Simla. After the First World War (1914–18) the department was expanded and the office was shifted to Poona. At present there are some 350 observing stations in India. These are grouped into five classes. The first class observatories have, along with eye-reading instrument, self-recording instruments also. They transmit observations twice daily to the forecasting stations. The second class stations have generally only eye-reading instruments and they also transmit telegraphic weather messages twice daily; the third class observatories differ from the second class in that they transmit observations to the forecasting centres only once a day. The fourth class stations record only temperature and rainfall conditions and they do not telegraph messages daily. The fifth class stations only record rainfall and they telegraph at 8 hours local time the amount of rainfall during the past 24 hours.

At fixed hours in the first, second and third class observatories, the trained observers read the barometer or barograph, note the temperature, the direction and speed of winds, the amount and type of cloud, the amount of precipitation, if any, and visibility. All these results are transmitted by code to the forecasting stations. These are supplemented by observations from the fourth and fifth class stations and also by the weather messages, received from ships approaching the coast. Since the messages are sent by telegraph or wireless they are received in a short time at the central office where the

observations are immediately entered on a weather map. Upper air observations which help in forecasting are procured from hill stations, aeroplanes, pilots, balloons, etc., and are plotted separately. (Examples of Indian and foreign weather maps are given in Figure 173.)

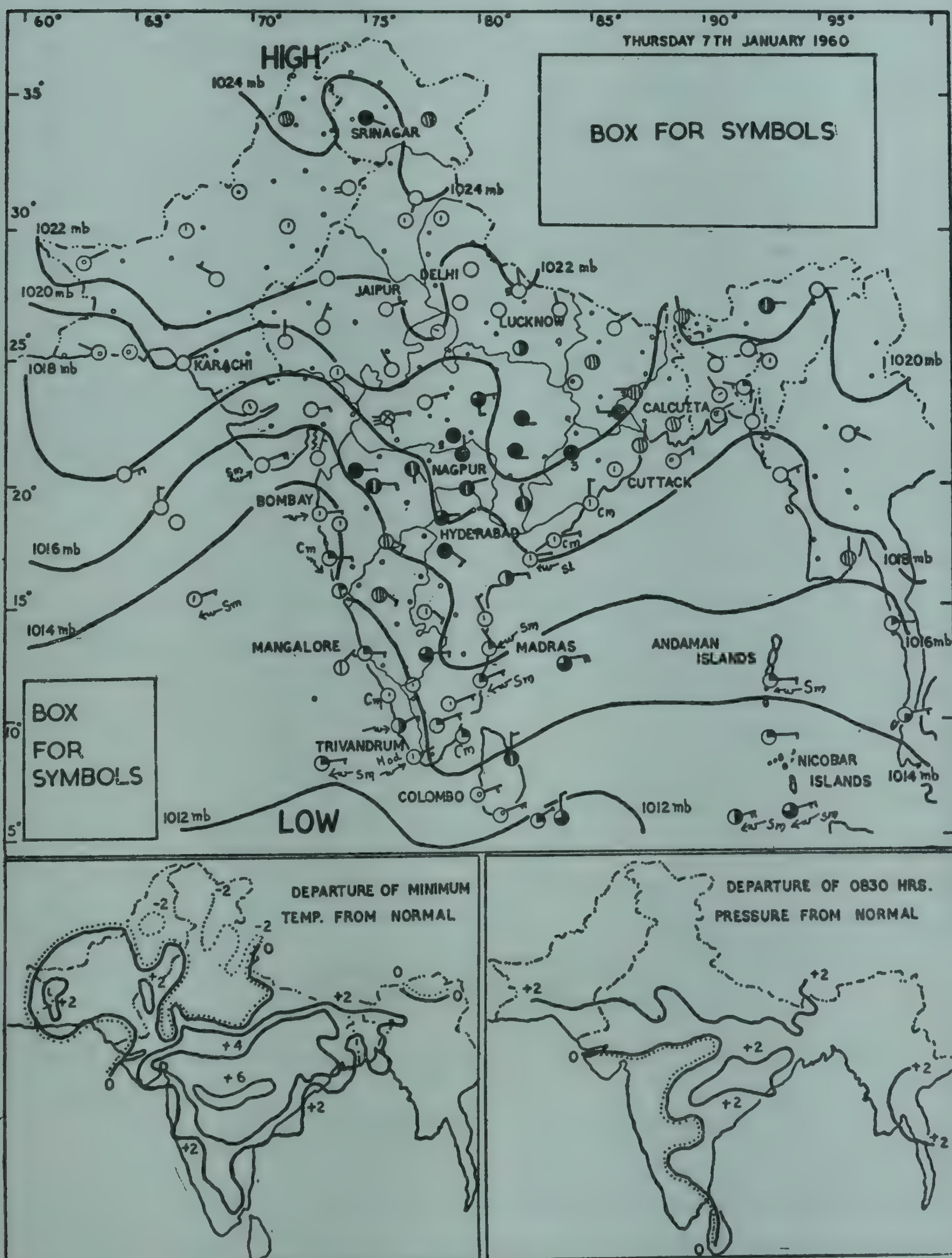


Figure 173 a : An Indian weather map

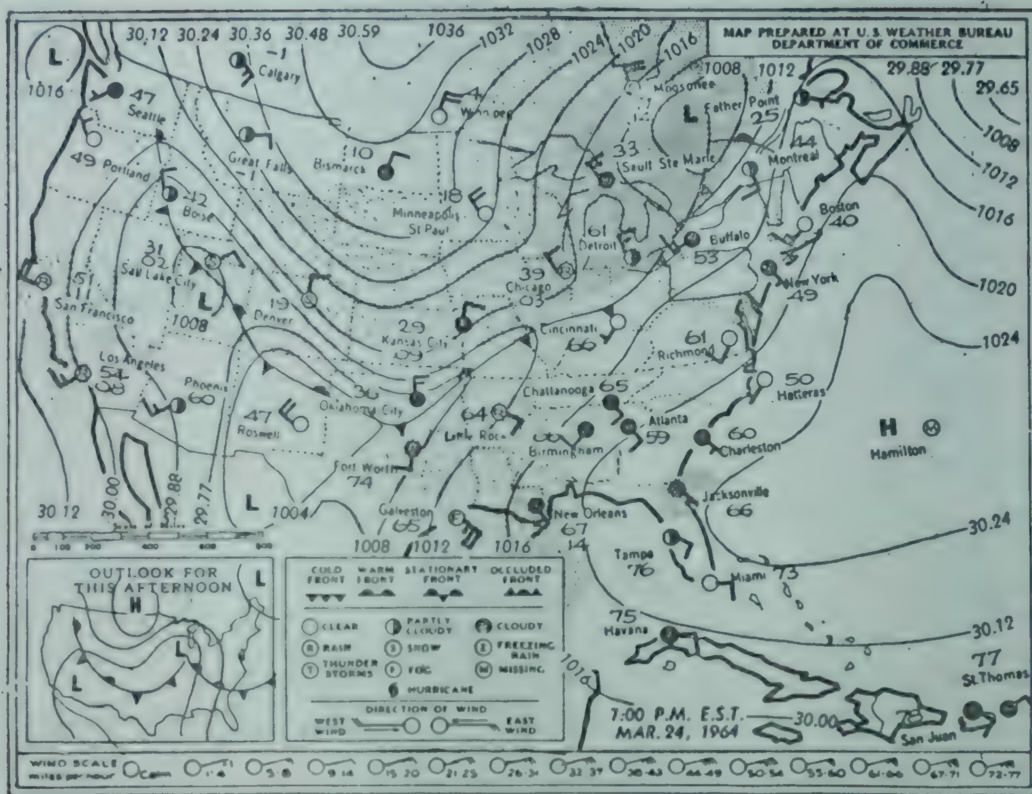


Figure 173 b : An American weather map

Schematic Representation :

Schematic representation of weather is as common as synoptic mapping. Such diagrams are used to explain the dynamic nature of various weather elements. For example see Figure 174.

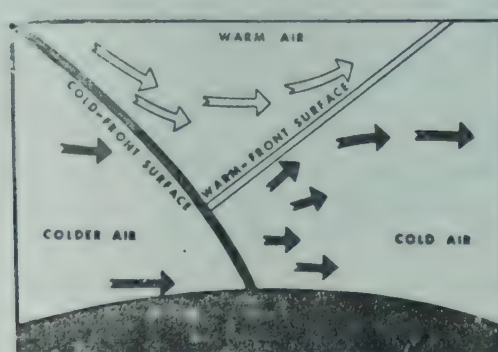


Figure 174 : An example of the schematic representation of weather data

MAPPING THE CLIMATIC DATA

Iso-lines :

Much of the climatological data is represented by line symbols. The most common among these symbols are the isametric lines. When depicted on maps, the isametric lines give what we call isopleth maps. Isametric lines

can be applied to any climatic data. Isopleths may be interpolated for places having the same mean values of temperature, rainfall, pressure, sunshine, frost, clouds, relative humidity and so on. Some of these isametric lines are given below.

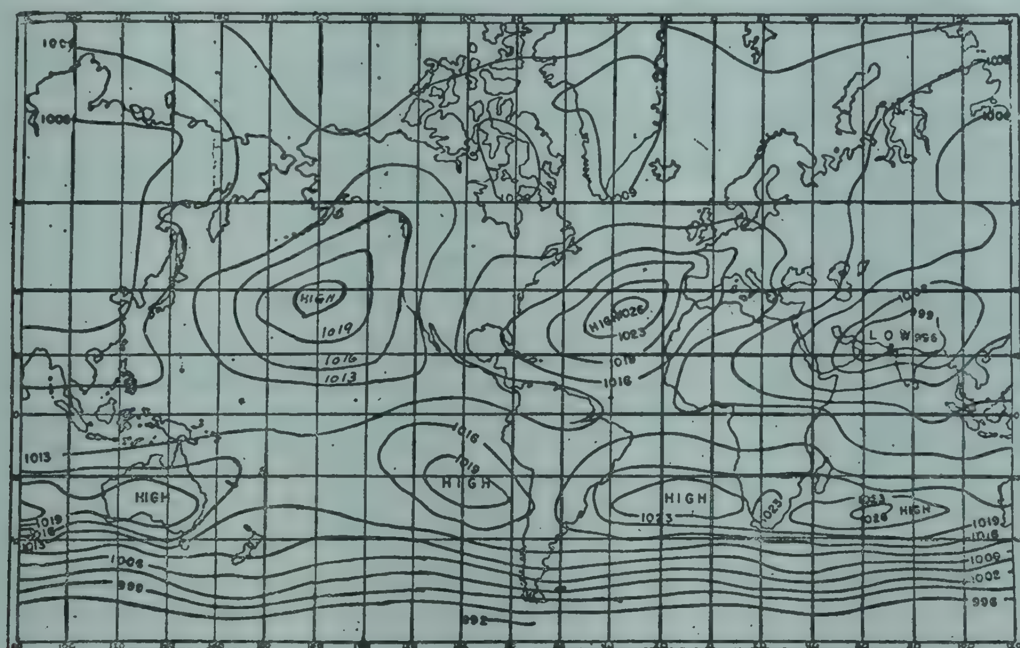


Figure 175 : World Map showing the July pressure gradients

Isobars : Lines connecting places of same pressure (Figure 175)

Isotherms : Lines connecting places having same temperature

Isohyets : Lines connecting places having same rainfall

Isomers : Lines connecting places having same monthly rainfall average shown as a percentage of annual total.

Isohels : Lines connecting places having same mean daily duration of sunshine.

Isanomals : Lines connecting points having same temperature deviation from the standard temperature of the points. The standard temperature for a latitude can be calculated by the formula :

$$t = -17.8 + 44.9 \, \mathrm{Cos}^2 \, (\theta - 6°\text{–}30') \; °C$$

Where θ = latitude.

Isa-frequencies : Connect places having the same mean frequency of a climatic phenomenon, expressed as number of days or number of occasions per year in which they occur.

Isorymes : Lines connecting places having same mean value of frost.

Isonaphs : Lines connecting places having same mean value of cloud cover.

Equipluves :

Lines joining places with same pluvimetric coefficients are called equipluves. The pluvimetric coefficient for any month can be derived by using the following formula :

$$\text{Pluvimetric coefficient} = \frac{t}{T \dfrac{Dm}{N}}$$

t = total rainfall of a particular month.
T = total rainfall of the station for the whole year.
Dm = number of days in that particular month.
N = number of days in the year (365)

For example :

Table 21. *Rain-fall data for Kanpur.*

Months.	J	F	M	A	M	J	J	A	S	O	N	D	Total
Rainfall In (inches)	0.6	0.3	0.3	0.2	0.4	3.1	9.7	10.2	5.5	1.2	0.2	0.3	32.0

The pluvimetric coefficient for August

$$= \frac{10.2}{32.0 \left(\dfrac{31}{365}\right)} = 3.7$$

Equivariables :

The distribution of places with similar deviations from their average weather conditions can be shown with the aid of isopleths. This can be done by finding out the coefficient of variability for each station. The following formula can be used for calculation :

$$CV = \frac{\sigma \ (100)}{\overline{X}}$$

Where CV = Co-efficient of variability
σ = Standard deviation
$\overline{X}$ = mean value.

Equi-correlatives :

We can calculate co-efficients of correlation between the rainfall data pertaining to pairs of stations, and draw isametric lines showing same correlations. The formula for calculating the co-efficient of correlation is

$$r = \frac{\frac{1}{n} \Sigma (x - \overline{x}) \quad (y - \overline{y})}{\sigma x \quad \sigma y}$$

r = Co-efficient of correlation.
n = number of years of observation.
x = annual precipitation for the first station.
y = annual precipitation for the second station.
$\bar{x}$ = mean annual precipitation for the first station.
$\bar{y}$ = mean annual precipitation for the second station.
σx = Standard deviation for x
σy = Standard deviation for y
(Note: Further details regarding the co-efficient of correlation are given in chapter on collection and interpretation of statistical data.

Isopleths for aridity and moisture :

Aridity is an important factor in the delimitation of climatic regions and in agricultural planning. It can be determined with the help of the following formula and used to prepare isopeth maps.

R. Lang's formula :

$$\text{Rain factor} = \frac{\text{Annual preciptation in millimeters}}{\text{mean annual temperature in degree centigrade}}$$

Miller's formula :

$$\text{Index of humidity} = \frac{T}{R}$$

T = mean annual temperature in degree fahrenheit.
R = mean annual rainfall in inches.

De Martonne's formula :

$$I = \frac{P}{T + 10}$$

I = Index of aridity
T = mean annual temperature in degree centigrade
P = mean annual rainfall in mllimeters.

Thornthewaite's formula :

P/E = Precipitation — evaporation ratio

$I = 11.5\left(\dfrac{P}{t - 10}\right)\dfrac{10}{9}$. The summation of the twelve monthly values, multiplied by 10 to avoid decimals, gives the values for the year. Index values range from 0 to 150, giving five categories.

Thermal efficiency factor :

$$I = \frac{t - 32}{4}$$

t = mean monthly temperature.

Line graphs :

Line graphs to show a variety of data are and can be used advantageously. We can show the monthly variation in temperature by putting months on the X axis and temperature on the Y axis. Graphs to represent the temperatures of more than one town can also be drawn to give a comparative picture. (Figure 176). Graphs can also be used to show trends in average precipitation or to show percentage departure from mean rainfall as shown in Figures 177 and 178.

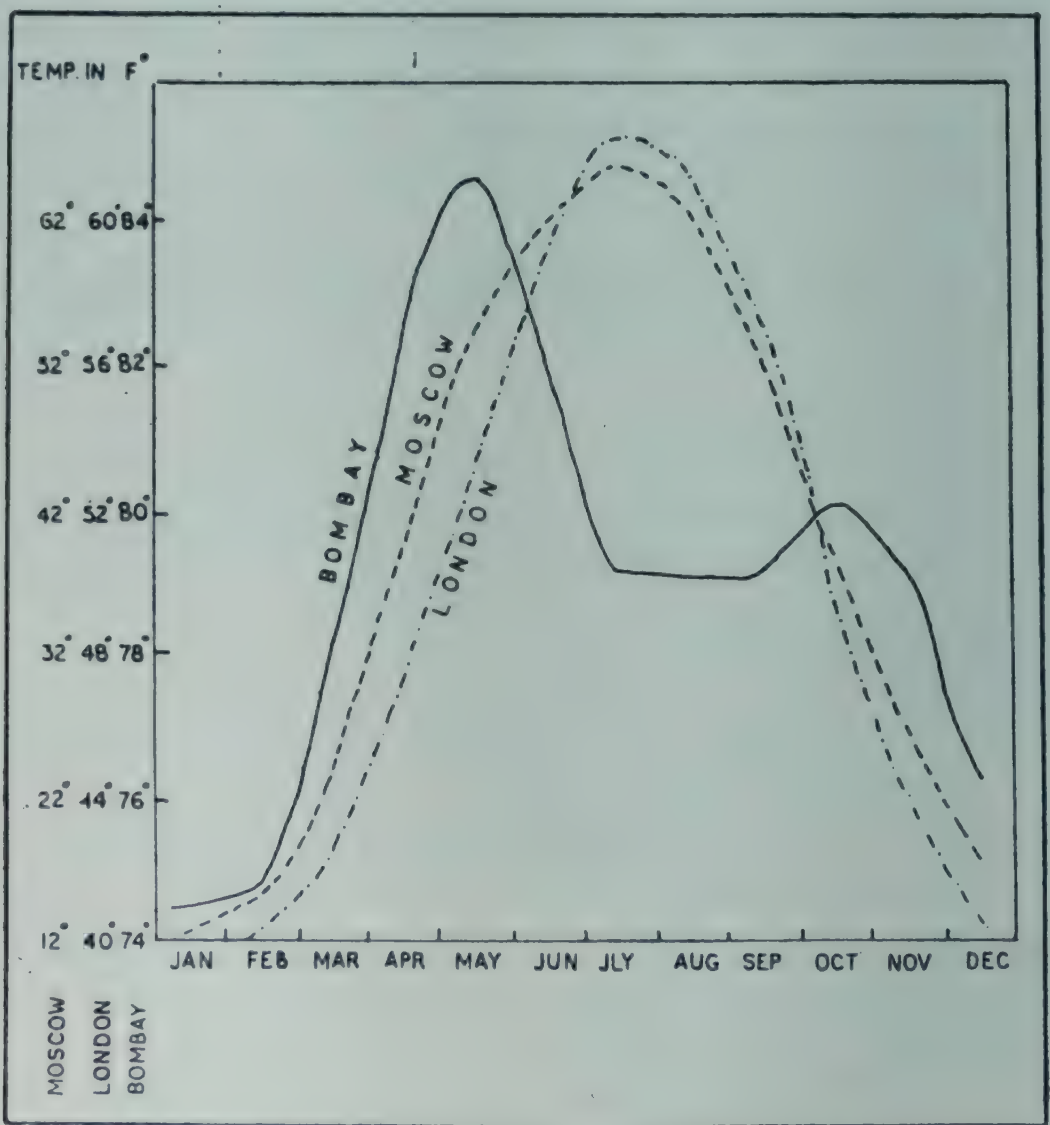


Figure 176 : Line graphs showing monthly temperature at Moscow, London, and Bombay.

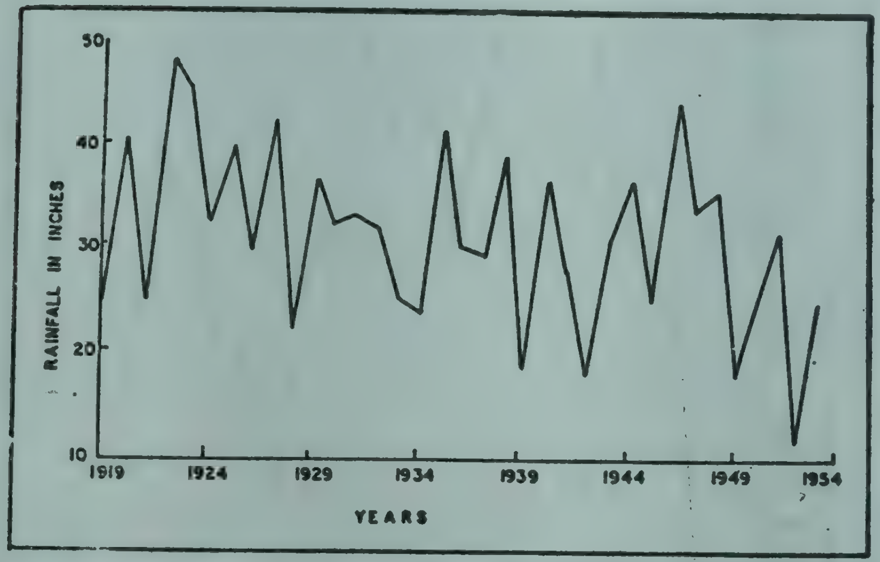


Figure 177 : Line graph showing average precipitation at Tirunelveli.

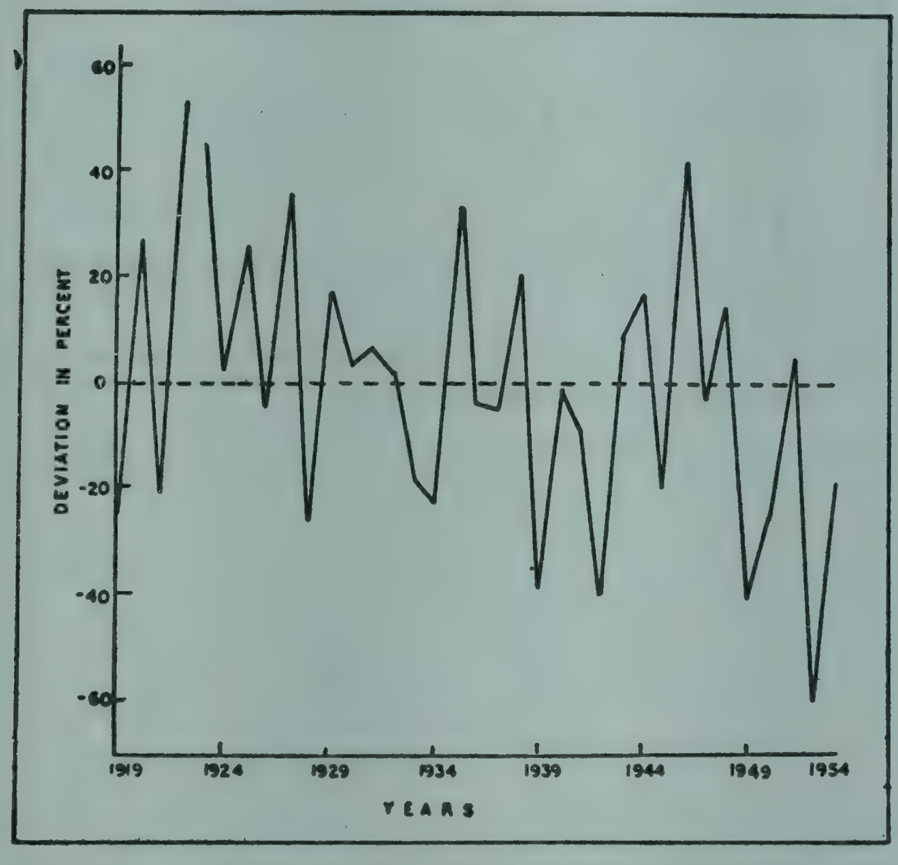


Figure 178 : Line graph showing percentage deviation of rainfall at Tirunelveli.

A graph showing the accumulated percentage deviations also show the cyclic fluctuations and trends in temperature and rainfall. For this type of graph, annual deviations from the mean annual rainfall or from any other base are obtained by subtraction and the accumulated deviations are obtained by additions (Table 22 and Figure 179).

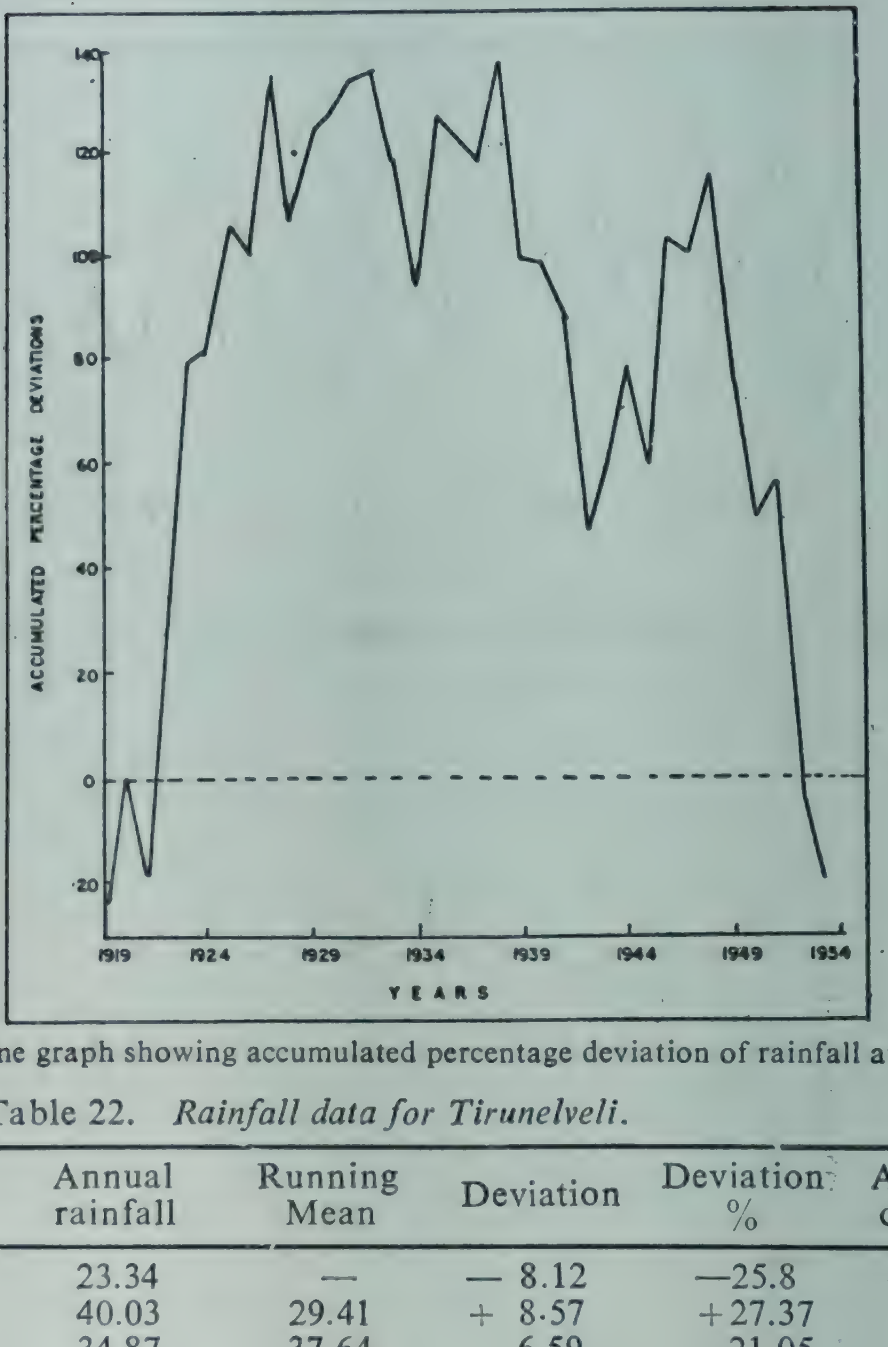


Figure 179 : Line graph showing accumulated percentage deviation of rainfall at Tirunelveli.

Table 22. *Rainfall data for Tirunelveli.*

Year	Annual rainfall	Running Mean	Deviation	Deviation %	Accumulated deviation %
1919	23.34	—	— 8.12	—25.8	— 25.8
1920	40.03	29.41	+ 8·57	+27.37	+ 1.57
1921	34.87	37.64	– 6.59	—21.05	— 19.48
1922	48.02	39.55	+16.56	+52.89	+ 33.41
1923	45.76	41.97	+14.30	+45.66	+ 79.07
1924	32.13	33 06	+ 0.67	+ 2.14	+ 81.21
1925	39.13	33.72	+ 7.84	+25.03	+106.24

Frequency graphs :

It is possible to show the frequency of extreme temperature, heavy rainfall etc. by graphs. A histogram is typical example of frequency graphs. We can plot a histogram showing the frequency of a given amount of rain during a given period. The amount of rain is plotted on X axis and the percentage or frequency on the Y axis. Figure 180 illustrates a histogram of this type.

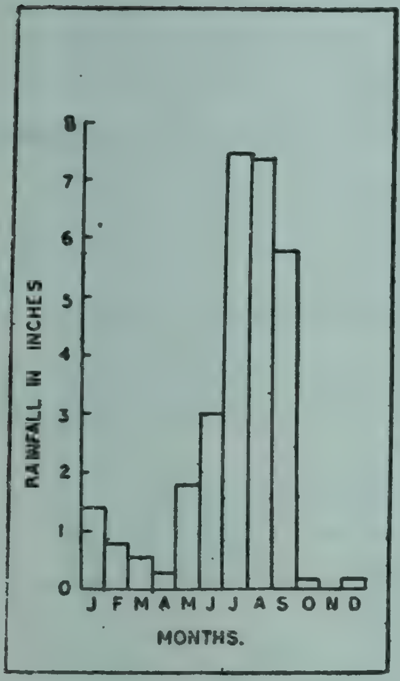


Figure 180: A histogram showing monthly rainfall at New Delhi.

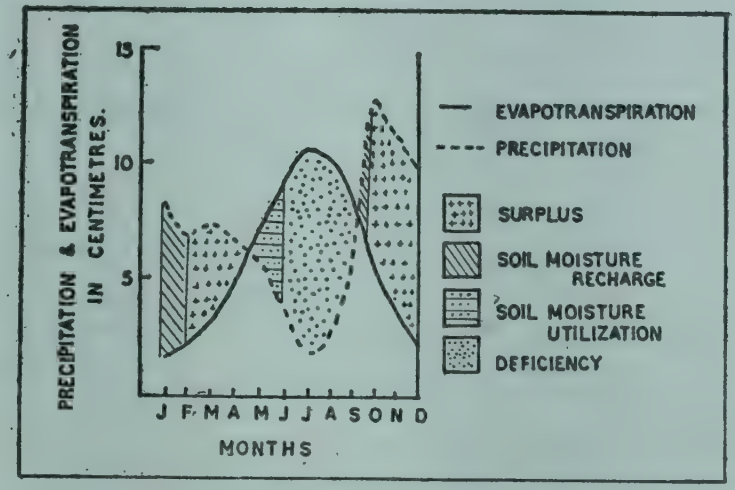


Figure 181: Water surplus graph for Rome, Italy.

Water surplus graphs:

These graphs can be grouped under line graphs. In this graph, the mean monthly evapo-transpiration and the mean monthly rainfall are superimposed upon each other in order to analyse the local climate in terms of seasonal moisture surplus and rainfall efficiency (Figure 181). The following example of Rome illustrates the principle behind this graph (table 23).

Table 23

Month	Temperature (°C)	Rainfall (cms)	P. E. (Pontential evapotranspiration) (in cms.)
January	7.0	8.128	1.6
February	8.2	6.85	2·0
March	10·5	7.36	3.0
April	13.72	6.60	4.6
May	18.0	5.59	7.0
June	21.60	3.81	9.0
July	24.5	1.78	10.5
August	24.1	2.54	10.0
September	24.8	6.35	9.0
October	16.5	12.7	5.5
November	11.6	11.18	4.0
December	8.0	9.91	2.0

Climatographs:

Several climatic phenomena can be depicted by climatographs. It was devised by E. N. Munns and later elaborated by Hartshorne. Here the plotting is done from the centre of the circle outward with the help of a graduated table which is based on the following formula.

$$r = \frac{x\,(\text{colog. } t)}{100}$$

r = required distance from the centre for marking the temperature point.

x = distance from the centre of the circle to zero degree fahrenheit.

t = the particular monthly temperature.

Table 24 : *The following table shows the required calculation.*

Madras :	75.3	76.6	79.5	84.1	88.7	88.4	85.7	84.5	83.9	80.8	77.9	75.7
$\frac{(\text{colog } t)\,x}{100}$	.85	.88	.93	1.04	1.16	1.15	1.08	1.05	1.04	.96	.90	.86
Tokyo :	37.2	38.3	44.1	54.3	61.5	68.9	75.0	77.7	71.6	60.6	50.4	41.4
$\frac{(\text{colog } t)\,x}{100}$	.35	.36	.42	.52	.69	.73	.84	.85	.78	.61	.48	.49
Peking :	23.5	29.3	41.0	56.7	67.8	76.1	78.8	76.5	67.6	54.5	38.5	27.3
$\frac{(\text{colog } t)\,x}{100}$	.26	.29	.39	.55	.71	.87	.92	.87	.71	.52	.36	.28

Note: The limiting temperature of hot water, cool, and cold seasons are assumed to be 68° F, 50 F°, and 32° F. Climatographs depicting the data given in table 24 are shown in figure 182.

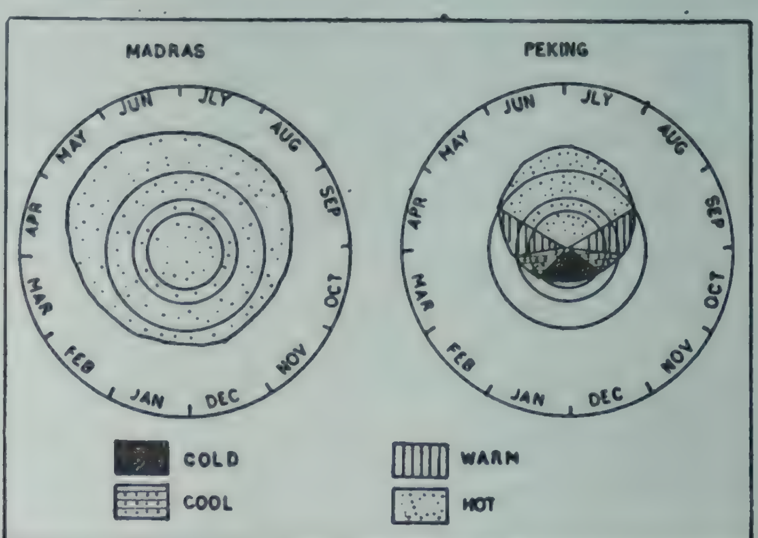


Figure 182 : Climatographs for Madras and Peking.

Wind Roses:

The average frequency and direction of wind at a place can be shown by a star-diagram also known as wind rose. There are a variety of wind roses among which superimosed wind roses and octagonal wind roses are more important.

Superimposed Wind Roses: The table 25 shows the percentage frequency of wind direction at various heights above the ground in Bangalore. With the aid of these data superimposed wind roses are drawn each representing readings at different ground levels and seasons. In this case, for the sake of clarity, frequencies are plotted from a central point and joined to form irregular octagons. (Figure 183).

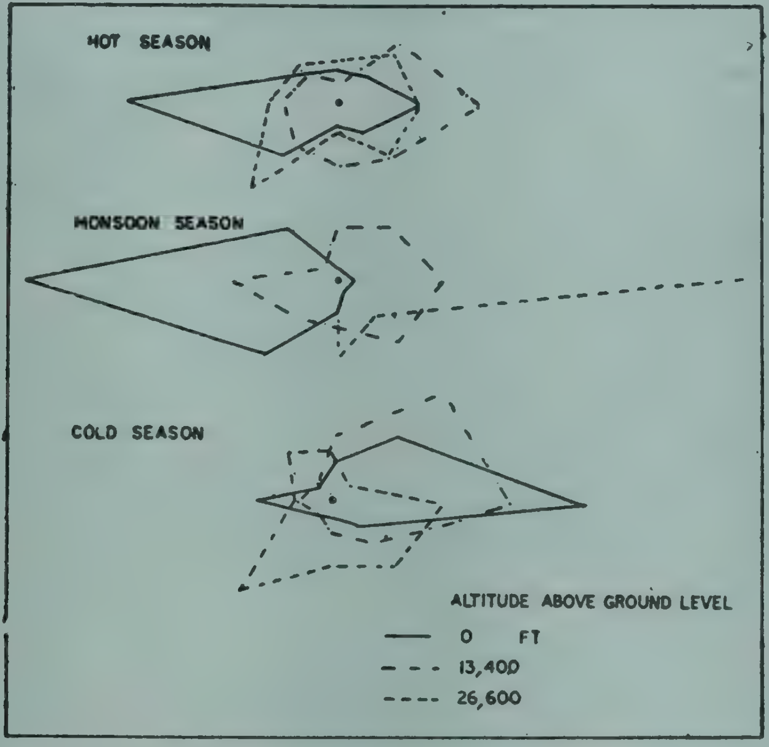


Figure 183: Superimposed wind roses for Bangalore.

Table 25

Season	Altitude	N	N.E.	E	S.E.	S	S.W.	W	N.W
	0′	6	7	15	7	4	14	39	8
Hot season	13,400′	4	16	26	14	11	11	10	8
	26,600′	8	13	15	13	5	23	13	10
	0′	1	1	3	1	6	19	56	13
Monsoon season	13,400′	10	14	19	16	9	10	19	3
	26,600′	0	0	75	10	15	0	0	0
	0′	7	17	46	6	3	4	14	3
Cold season	13,400′	12	28	31	10	6	3	6	4
	26,600′	9	4	20	16	11	23	7	12

Octagonal Wind Roses : Here the distance between the corresponding sides of each octagon represents a frequency of 12½ percent. The eight cardinal wind directions are represented, one on each side of the octagon. The twelve mean monthly frequencies of wind from each of these directions are plotted as columns. If winds were equally frequent from each direction, eight sets of twelve equal columns would result (Figure 184).

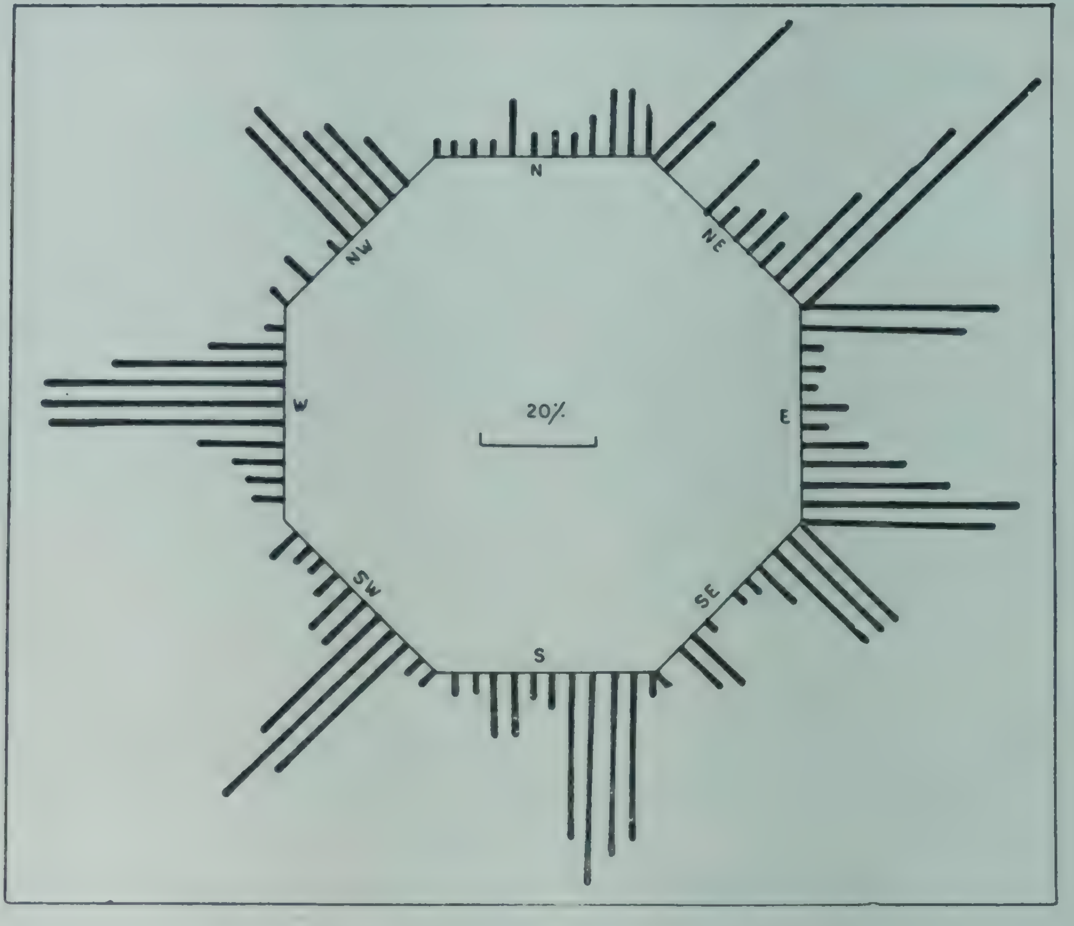


Figure 184 : Octogonal wind roses for Madras

Climograph or climogram or climagraph or climagram :

Here two climatic variables (monthly-means) viz. wet bulb temperature and relative humidity are represented on vertical and horizontal axes respectively (Figure 185). The four corners, N.E., N.W., S.W., and S.E. are marked as Scorching, Muggy, Keen and Raw respectively.

Another method is to use wet and dry bulb temperatures on the two axis. The wet bulb temperature is used on the y axis and the dry bulb on the x axis. Further details are given in figure 186.

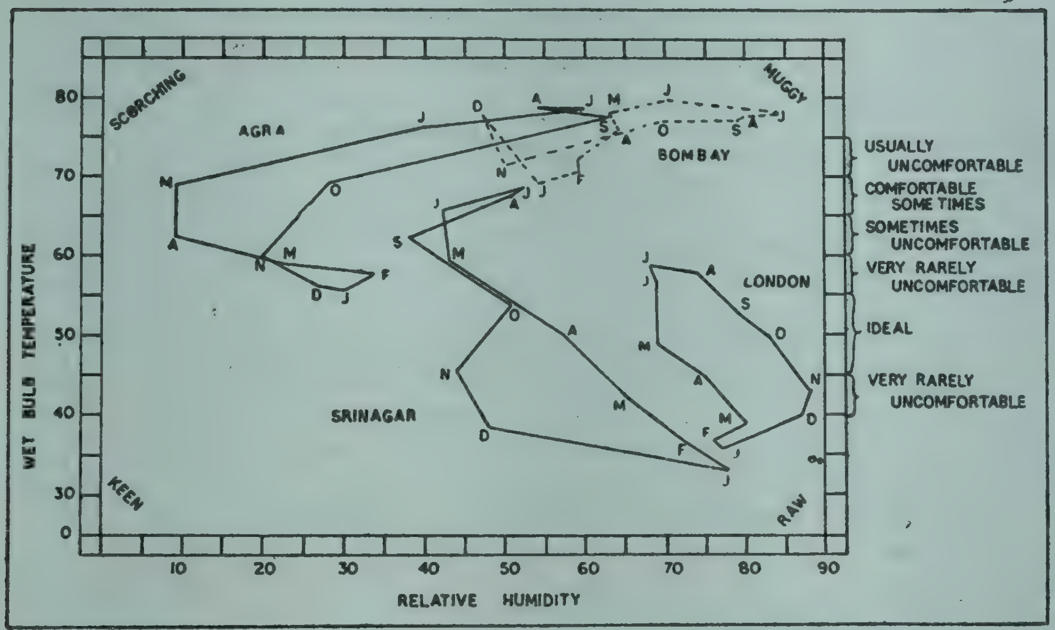


Figure 185 : Simple climographs for Agra, Bombay, Srinagar and London.

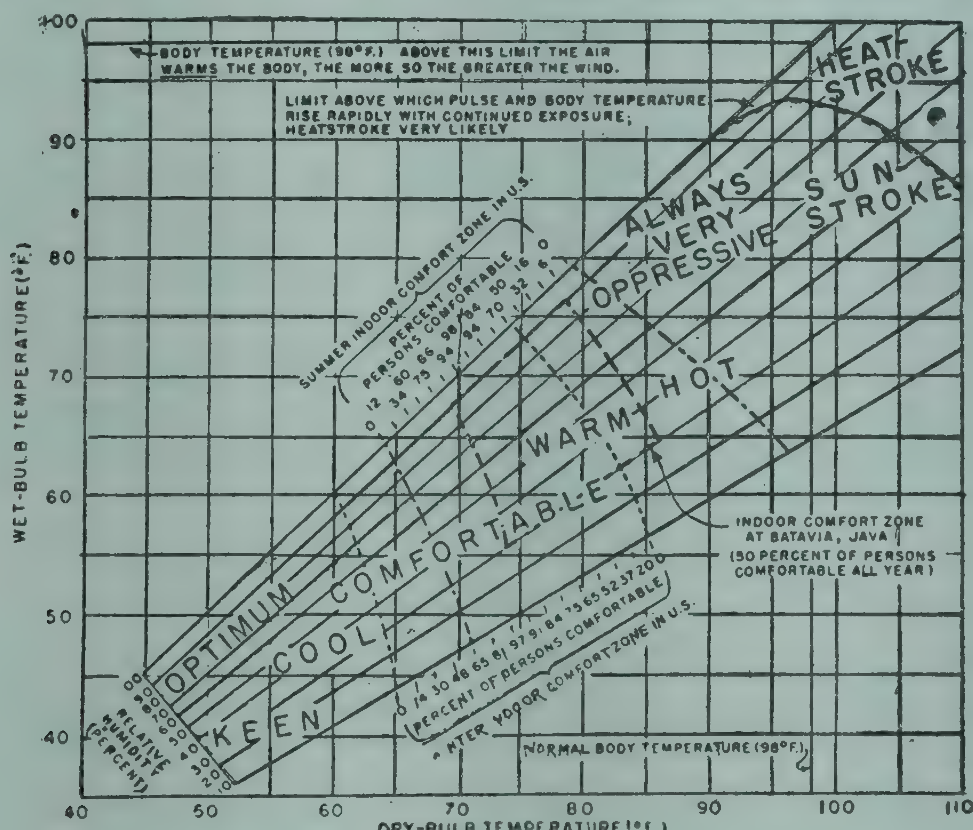


Figure 186 : Complex climograph

Hythergraph:

This is another type climograph. Here the mean monthly temperature is plotted on the ordinate and the mean monthly rainfall on the abscissa. (Figure 187). With the aid of this graph one can analyse the climatic differences in relation to human activity.

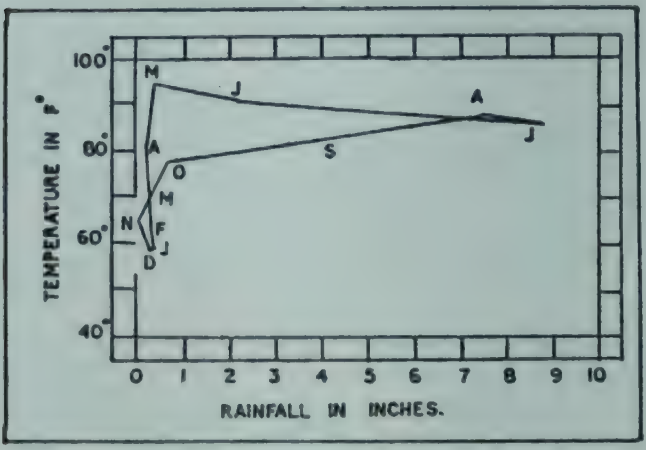


Figure 187: Hythergraph for Calcutta

Rainfall Dispersion Diagram:

It is an important tool in the analysis of rainfall distribution. Here rainfall is represented on the vertical axis and the months on the horizontal axis. The amount of rainfall can be plotted by means of dots of suitable sizes against each month for each year.

It may be pointed out in this connection that at least a thirtyfive year record of rainfall should be available for the above analysis. A rainfall dispersion diagram for Tirunelveli District is shown in figure 188.

The median or middle value of rainfall can be found out by selecting the value which lies between the two extremes of rainfall at either end of the series. For instance in a thirtyfive year series, the eighteenth value from minimum is recognised as the median value. The lower quartile value in this case lies between the nineth and the tenth figures.

Ergograph:

The relationship between season, climate and crops can also be represented graphically. Here, along the vertical axis are given the monthly average temperature, rainfall and relative humidity. The twelve months are marked on the horizontal axis. The acreage of various crops is shown below the horizontal axis on a selected scale. The net acreage of each crop is given in separate rectangular blocks. The length of each block should correspond to the growing season and its breadth is calculated according to a selected scale (Figure 189). A Circular ergograph showing the amount and nature of work done during each month or season of the year has been suggested by A. Geddes and A. G. Ogilive. It is illustrated in Figure 190.

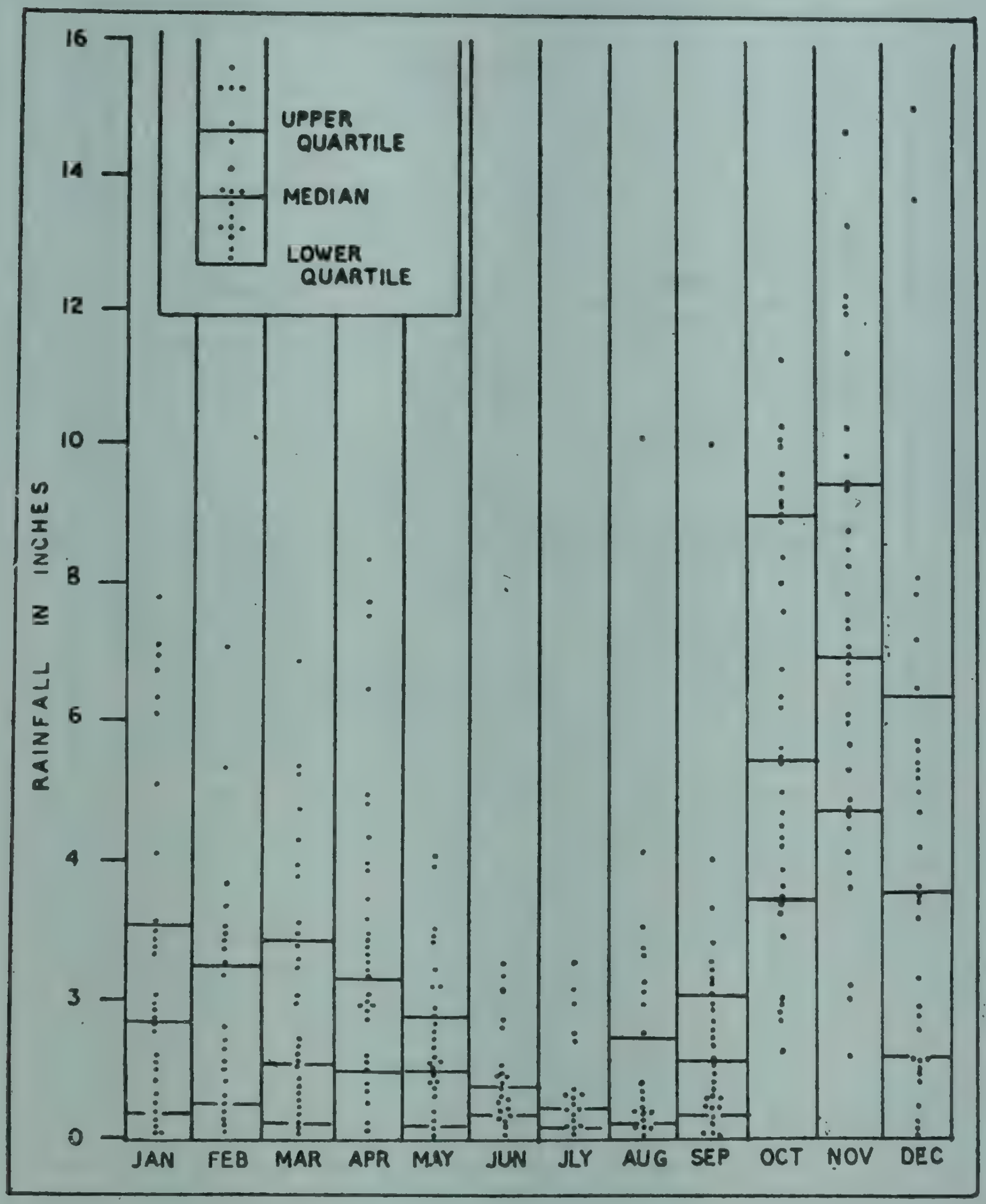


Figure 188 : Rainfall dispersion diagram for Tirunelveli.

Columnar graphs :

Because of their clarity and ease of construction, they are very effective in the depiction of certain aspects of climatic data. They can be used to show rhythm of diurnal and seasonal ranges and the range and variability of various climatic elements.

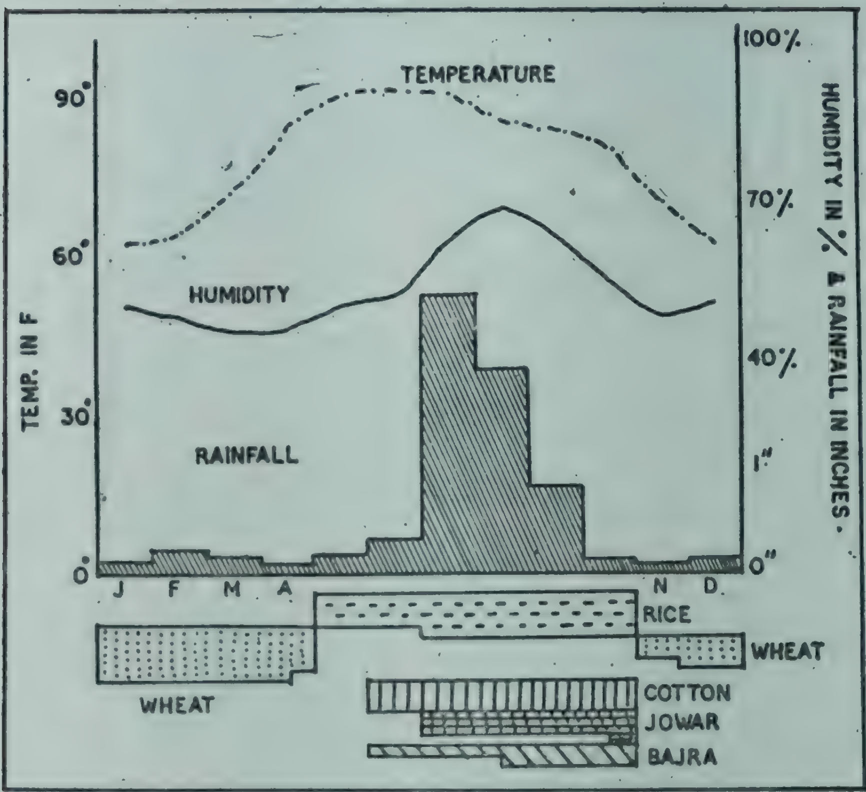


Figure 189 : A simple ergograph for Sind

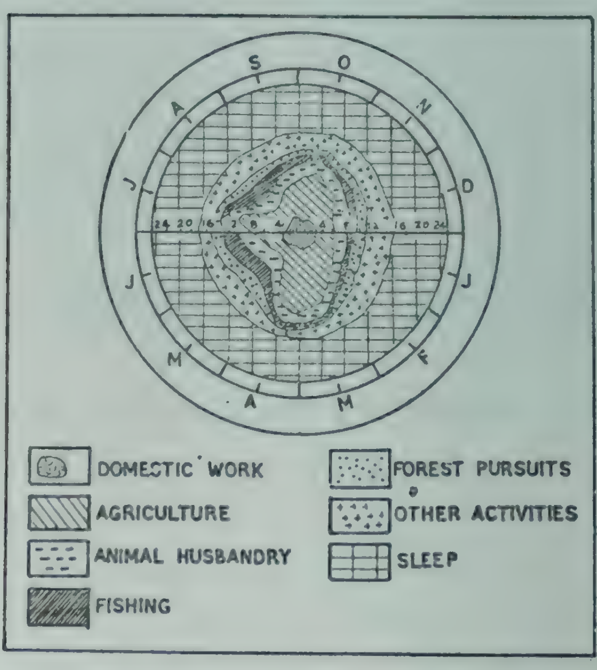


Figure 190 : A circular ergograph for Tharus

In a simple columnar diagram each vertical column represents a certain value of rainfall, sunshine etc., for a particular period of time viz. monthly (to show seasonal variation) or daily (to show daily variation). Such diagrams can also be constructed to show total amount of rainfall (Figure 191).

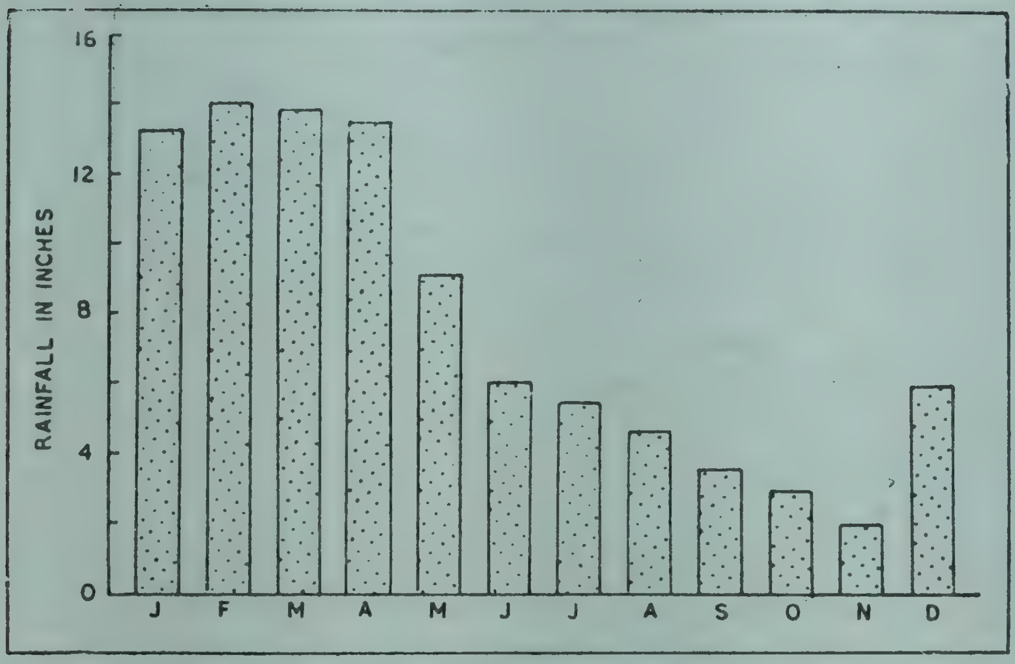


Figure 191 : A simple columnar diagram for Brazil

For comparative purposes percentage columnar diagrams can be made. In this case each of the monthly columns will represent percent of annual rainfall. For further details columns can be sub-divided in two divisions one showing rainfall and the other showing snowfall. Similarly the columns may be sub-divided to show more details.

Deviations from mean conditions may also be effectively depicted by columnar diagrams. For example, columns may be constructed to show the maximum, mean, and the minimum rainfall in each month. Further elaborations may be introduced by indicating the standard deviation and the probable deviation of rainfall from the accepted mean. Such diagrams are known as hyetographs. We can also show temperature variations in more detail to give not only the mean but also the mean daily minimum and maximum, mean absolute monthly minimum and extreme maximum and minimum records. Similarly we can show variations in pressure.

Arrows :

There are a variety of data which can be represented by arrows. For instance the horizontal movement of air over the surface of the earth, trajectories of air, wind direction etc. can be shown by changing the direction and width of arrows (Figure 192).

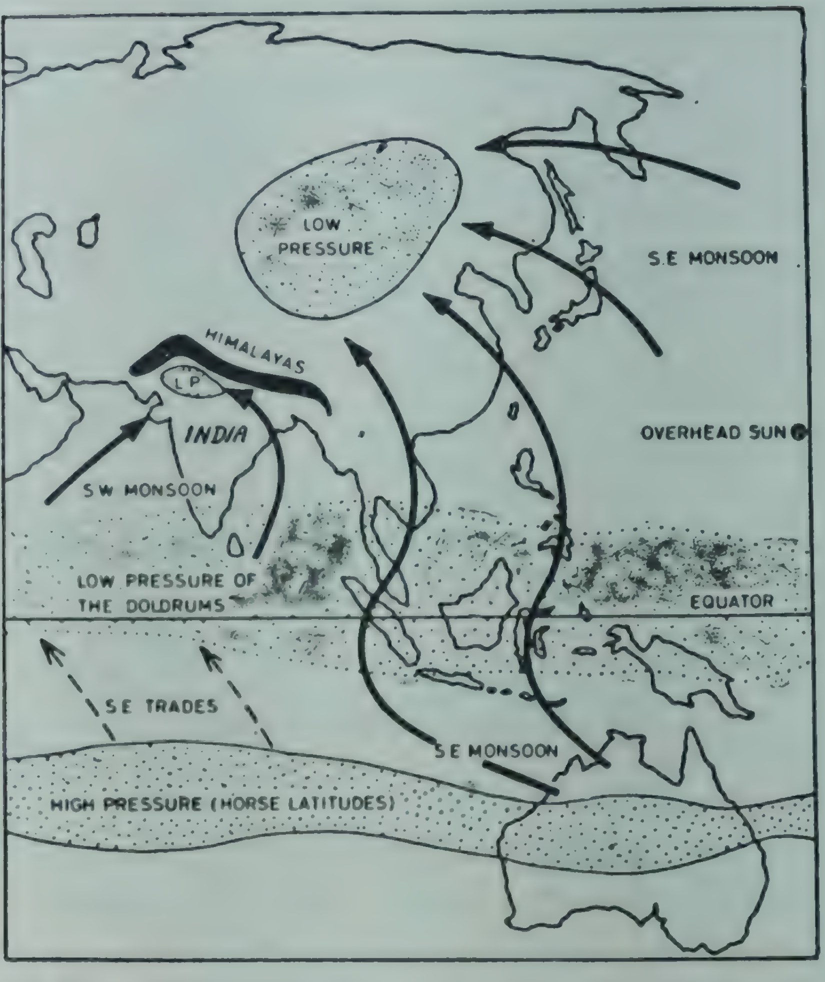


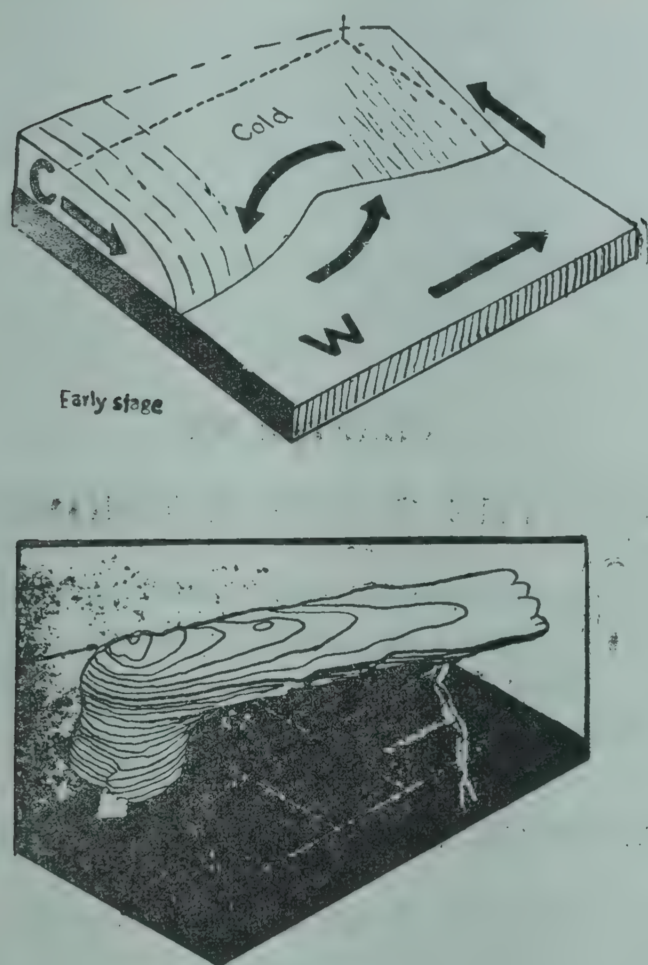
Figure 192: Arrows showing the dircetion of winds.

Three-dimensional Diagrams:

Lot of climatological data can be represented by three-dimensional diagrams in the same way as we represent the terrain. Jenks has attempted to represent a number of climatic features in this way. The technique is not difficult to follow because all that we have to do is to treat various types of iso-lines as contour lines. Block diagrams also can be made. Examples of some of these diagrams are given in Figure 193.

Distributional maps:

Climatic maps showing the distribution of a variety of climatic data are only too common to need introduction. Isopleth maps can be drawn to show, for example, the distribution of rainfall. Choropleth maps are usually not made to depict such data. Cartograms showing the amount of rain received at various stations by means of bars, or the direction of wind by arrow are quite common.



(a)

(b)

Figure 193 : Three dimensional climatic diagrams : (a) early stage of a miot latitude cyclonse and (b) a thunderstorm with hail

Maps showing the association between two or more climatic elements can also be made. For example one can show the absolute rainfall as well as its variability in the same map (see figure 215).

CHAPTER XX

MAPPING THE SOCIO-ECONOMIC DATA

In the previous two chapters, we discussed the methods of representing the terrain and climatic data. This included the representation of both qualitative and quantitative data. In this chapter, we propose to discuss the methods of representing the various rypes of socio-economic data.

MAPPING THE QUALITATIVE DATA

In general there are three classes of qualitative data :

1. those which can be represented by point symbols ;
2. those which can be represented by line symbols ; and
3. those which can be represented by area symbols.

It should, however, be borne in mind that the symbols used for various data will vary with variations in the scale of the map. The data which can be shown by area symbols on a large-scale map may have to be represented by point symbols on a small scale map. A mining area may be taken as an example. On a large scale map it will be represented by an area symbol but on a small scale map it will be shown by a point symbol. On a small scale map one will find towns, capitals, cemeteries, churches, temples, light houses, bench marks, shafts, mines, hospitals etc. marked by symbols. But on a large scale map many of these are shown by area symbols.

Line symbols used in qualitative maps are those for roads, railways, telegraph lines, streams, boundaries, parallels and meridians to name a few. And the area symbols are used to show political units, deserts, vegetation, swamps, etc. etc. There are certain maps in which the symbols used represent quantitative values but they are rarely used for quantitative measurement of the data used. In this category fall the dot maps.

Problems of representation :

Symbols for qualitative data are not always drawn to scale. When we put a small dot to show the location of a town, the size of the dot does not have exact quantitative relation to the size of the town. Consequently all towns, big or small, are represented by the same symbol. Similarly a symbol showing the location of mines has no relations to the size of different mines.

Line symbols used for qualitative data have similar characteristics. The widths of streams, roads, railways or boundaries are not drawn to scale and their thickness is not necessarily based on their importance measured in quantitative terms. A river drawn on a map may have a width of 1/15th of an inch. The same river drawn on another map of the same scale may appear only 1/20th of an inch wide. Although political boundaries may be shown with lines having varying widths to distinguish them as international, national, state and local boundaries, their widths will not be in proportion (quantitative) to their importance. Boundaries can also be shown by different lines having the same width.

Area symbols showing qualitative values have the same characteristics. A forest area may be shown by any symbol (may be tree symbol) but this representation does not necessarily show the real areal-extent, nor does it show the density of the trees.

We often read in some of the text books that the population density of a certain area is thin or thick. These characteristics of density are also shown on maps. But such maps give only a qualitative value which always remains a matter for dispute. Terms like much, less, high, low, good, bad, hot, cold, rainy, dry etc. give only qualitative values. Unless these terms are backed by quantitative measures, they do not mean the same to everyone.

Types of qualitative maps :

The qualitative maps are of three types :

1. General reference maps
2. Pictorial maps
3. Thematic maps.

General reference maps : Most of the atlas maps that we see fall in this category. These maps specialize in giving locations of various places, political boundaries, transport networks, and prominent physical features. Such maps are often called multiple-use maps because they give a variety of imformation.

The purpose of these maps is to give as much information as possible without reducing the legibility of the map. Too much of cluttering reduces legibility. In such maps no single item of information is more important than the

other. In fact each one is important not only in itself but also for other items of information, for without putting them all together it is not possible to show the relative position of each other.

The general reference maps are of two types:

1. Atlas maps, and
2. Wall maps.

Atlas maps give more information than wall maps. Wall maps are made to be seen from a distance, whereas the atlas maps are to be read like a book. Because of this difference, wall maps give less of details, but whatever is given is given very prominently.

Thematic maps: In this category are included most of the historical, political and cultural maps. Some of the maps portraying socio-economic data are also qualitative in nature. Maps showing the networks of transportation lines and of irrigation canals can be given as examples of this type. At times book illustrations show the crops or mineral produced in different areas by symbols. These maps are not based on any quantitative value of area or production; they are designed to give only locational information (Figure 194). Thematic maps can also be pictorial. Pictorial maps are meant to show the distribution of various phenomena in a popular way. Children's encyclopaedia give a number of such maps (for an example see figure 195).

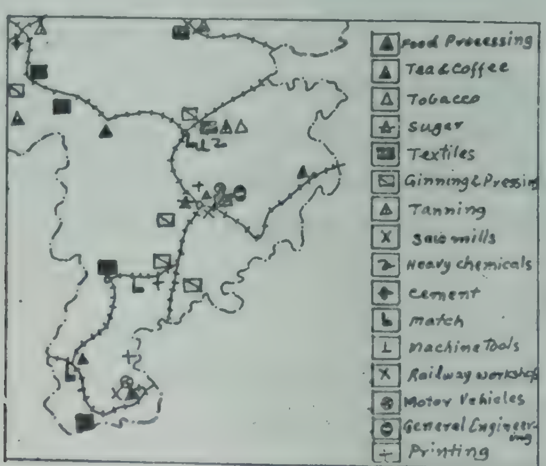


Figure 194

MAPPING THE QUANTITATIVE DATA

In the foregoing section we discussed how qualitative data are represented on maps. In this section we are going to deal with the methods of representing the quantitative data. It may be recalled here that while discussing the representation of terrain and climatic data we had discussed at length how

quantitative measurements can be depicted on maps. Some of the methods discussed there are going to be repeated in this chapter for they are also useful in the representation of the socio-economic data.

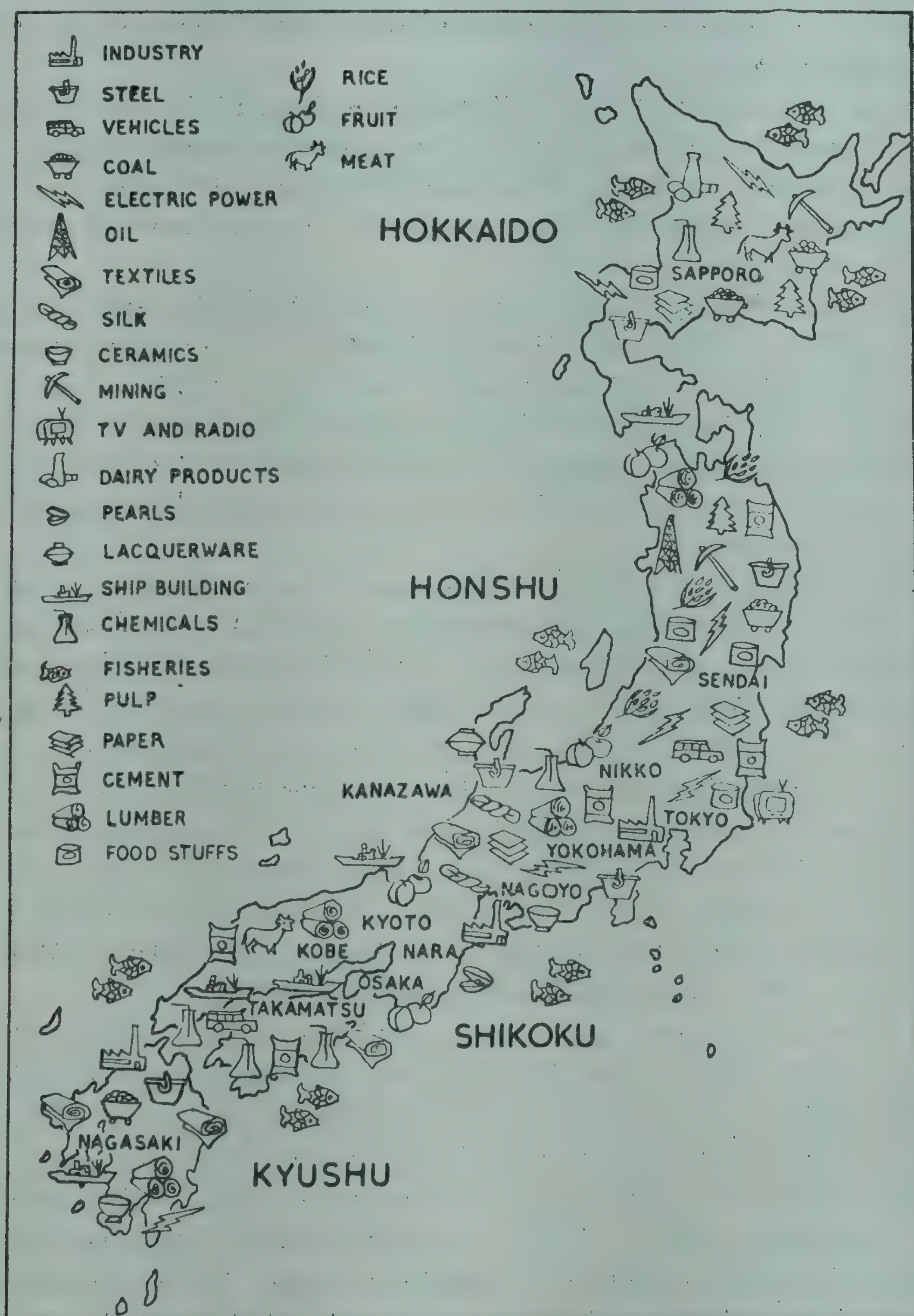


Figure 195 : A qualitative pictorial map showing distribution of industries in Japan

Mono-dot method:

Uniform size dots are used to show the distribution of a variety of socio-economic data. Dot maps provide a visual impression of relative density. But one cannot get the absolute figures from them unless one counts all the thousands of dots. Compared with other maps,. most of the dot maps are relatively easy to prepare because they do not involve complicated computations or manual skill.

Most dot maps show the distribution of a single phehomenon such as the people, livestock or acres of land. On a multi-coloured dot map, dots of different colours can be used to show more than one phenomena. Thus in a population map, urban and rural population can be shown in contrasting colours.

The size of dots selected for a dot map should be such that the map remains legible. At the same time, it should not be too large to produce a 'heavy' map. The size depends upon the density of the element to be represented. This should, however, be kept in view, that too few dots give an impression of sparse distribution while too many small dots give an impression of high density. In a dot map, the chief problem is the selection of a suitable size and value of dots.

Once the size and value of the dots have been selected judiciously, the general pattern of distribution will depend upon the areal unit of representation. If the units are large the probabilities of areal differences within these large units will be high. The dots have to be almost equally spaced within each areal unit. A civil division within a state may have no acreage under rice, but since other divisions included in the unit of representation have rice acreage, this particular division will also show rice acreage. Great care should, therefore, be taken in selecting the areal unit of representation. For a country like India, districts should normally be the units of representation. But if the scale is 1 : 1000,000 or so, one may have to go even to the Tahsil or Taluk level. Much will, however depend upon the availability of data.

Placing of the dots also poses a problem. Should the dots be equally distributed within the unit area for which data have been used? If the unit area is so located that on two sides of it there are high density units while on the other two sides are low density units, it will be desirable to put more dots on the side of high density areas and less on the other sides. Dots should not be placed over negative areas. Various accessory maps like physical, relief, etc. should be consulted to demarcate the negative areas. The most desirable state is one in which the dots are placed exactly where the elements to be mapped are located. For example, in population maps, the dots should be placed exactly

at the location of the towns and villages. If this is done the problem of distributing the dots will not arise. (For an example, see figure 196).

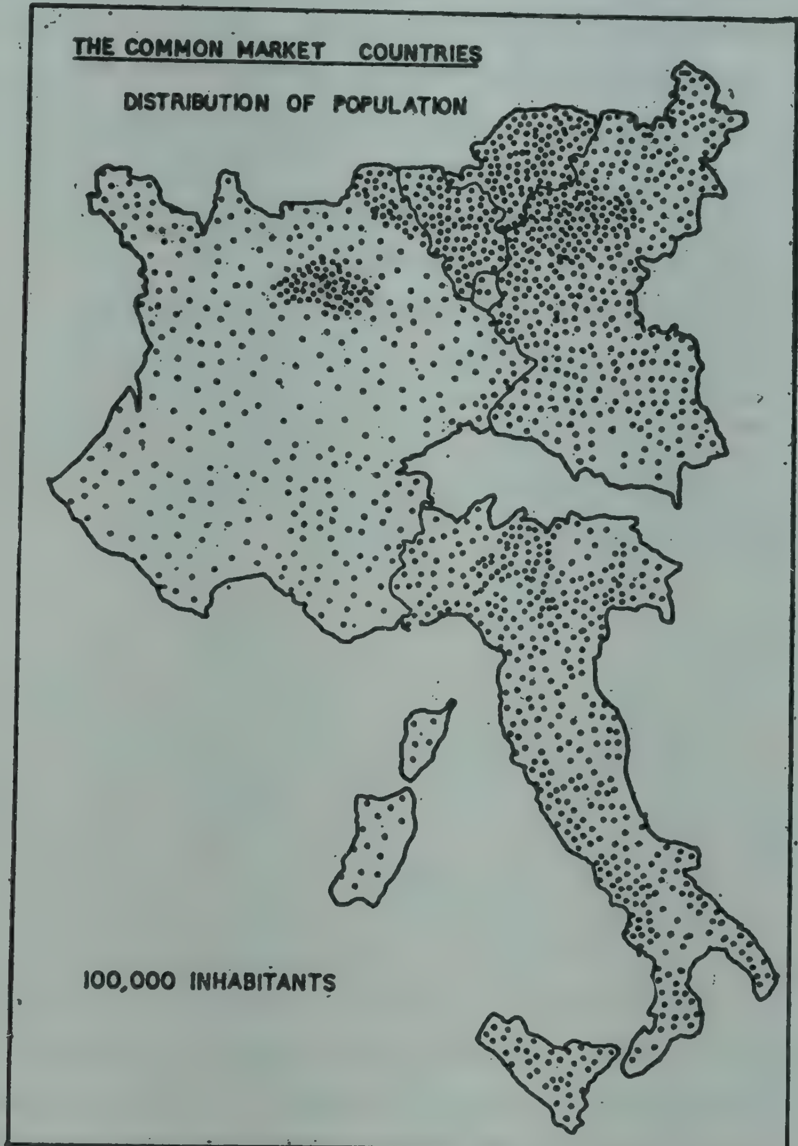


Figure 196 : Mono-dot method used to represent population density in the Common market countries.

Multiple dot Method :

In many areas the density of the element to be represented is so high that no matter how one proceeds mono-dot method can not give good results. If the dots represent large quantities, one faces the problem of residue. An area having 1,075,200 persons will be represented either by 10 or 11 dots, if each dot represents 100,000 persons. In either case, the representation will not be correct. The errors so generated can be minimised by reducing the values represented by each dot. This procedure will give more dots. This may, however, be used only if the map area in which the dots have to be placed, can

legibly accommodate so many dots. To further minimize this problem, multiple dot method can be adopted. In this system we have two or three sizes of dots standing for different values. In the above example, we can have a large dot representing 100,000 persons, a medium size dot representing 50,000 persons and a small size dot representing 25,000 persons. So, instead of putting ten or eleven dots, we can have ten large dots, one medium size dot and one small dot. This method is specially useful in showing population in a country like India. In certain areas the density is too high and in certain others too low and hence the mono-dot method does not give good results.

The National Atlas of India has used the multiple-dot method to show the distribution of population. Dots representing 100, 200, and 500 persons have been put exactly at the location of the villages and the towns. If a village has 800 persons, it gets one large, one medium and one small dot. Urban centres are represented by circles which are proportional to the population represented by them. (Figure 197).

Use of Dots and Circles :

Whenever the distribution of an element is too variable, dots and circles are put together. Multiple size dots are used to represent low density areas, and circles are used to represent large urban centres. The drawback of using circles lies in the fact that map readers tend to underestimate the size of a larger circle in comparison to the smaller ones. If two towns having 10,000, and 20,000 persons respectively are represented by proportional circles, the circle representing 20,000 persons would not appear twice the size of the circle representing 10,000 persons. Flannery has suggested the following alternative method of calculating the radius of a circle. The conventional method is to take the square root of the data and then construct circles with radii proportional to the square root.

1. Determine the logarithm of the data,
2. Multiply the logarithm by 0.57,
3. Determine the antilogarithm of the product, and
4. Divide the antilogarithm by the chosen unit value to get the radius of the circle.

This method of calculating the radii of circles is better and is recommended for use. The circles should neither be too large to get mixed up or to indicate too much fullness nor too small to indicate emptiness. At times two or more circles overlap. To make each of the circles distinct, the following two methods are recommended :

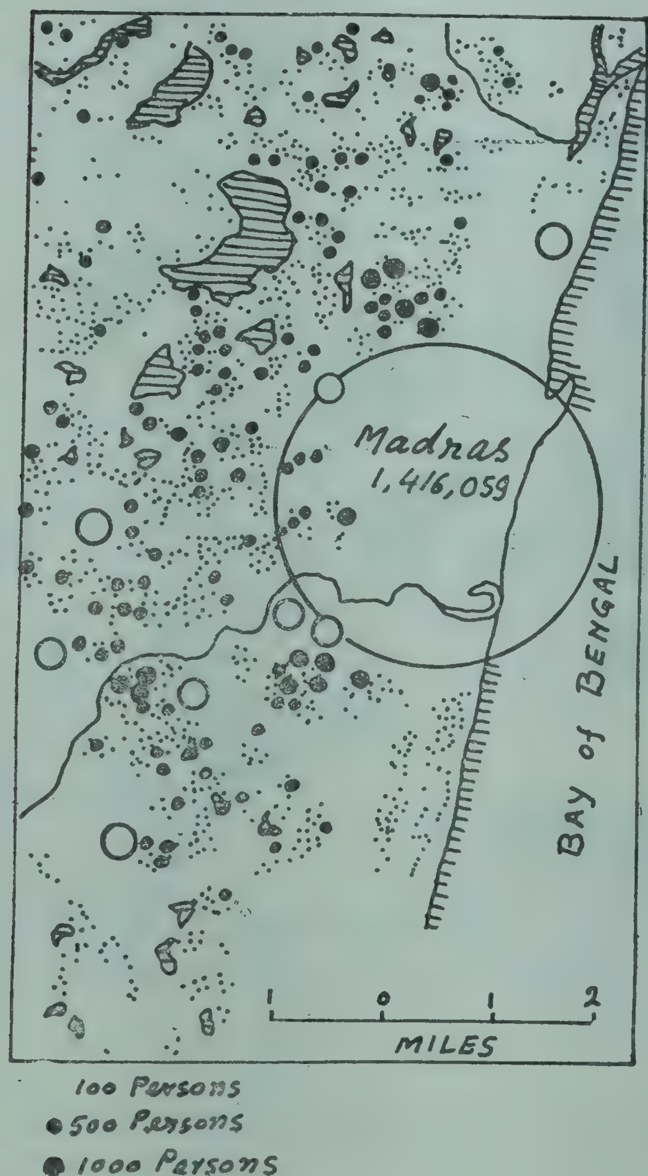


Figure 197: Map of Madras and its environs showing density of population by multiple dot method.

1. Keep the circle transparent so that their boundary lines are visible; or
2. Fill up the circles with patterns or solid colours but allow a narrow opening between them. The larger circle should be cut to accommodate the smaller ones. (Figure 198)

Circles can be used only if the range of data used is not too large.

Use of Spheres :

If the range of the data is too large, circles cannot be used effectively to show both ends of the range. In such situations spheres can be used in place of circles. To get the radii of spheres we have to calculate the cube roots

Figure 198 : Representation of the population of Southern Tamilnad towns by cirles.

of the data. The method of representing quantitative data by spheres is illustrated in Figure 199.

Pie Charts :

Pie or circle charts are made to show fractions of a total.

Example : Prepare a pie chart to represent the following data :

Total land area	1000,000	acres
Area cultivated	600,000	,,
Area under forest	300,000	,,
Waste land	100,000	,,

The total area will be represented by a circle of any convienient radius. The whole circle is represented by 360°. So the cultivated area will be represented by $\frac{360^\circ \times 3}{5} = 216^\circ$. The segment of the circle formed by 216° will represent the cultivated area. We can determine the segments of the circle for other uses in the same way. Pie charts can also be used in conjunction with maps (Figure 200). In such cases the circles drawn will have to be proportional. Perspective pie charts also can be drawn as illustrated in Figure 201.

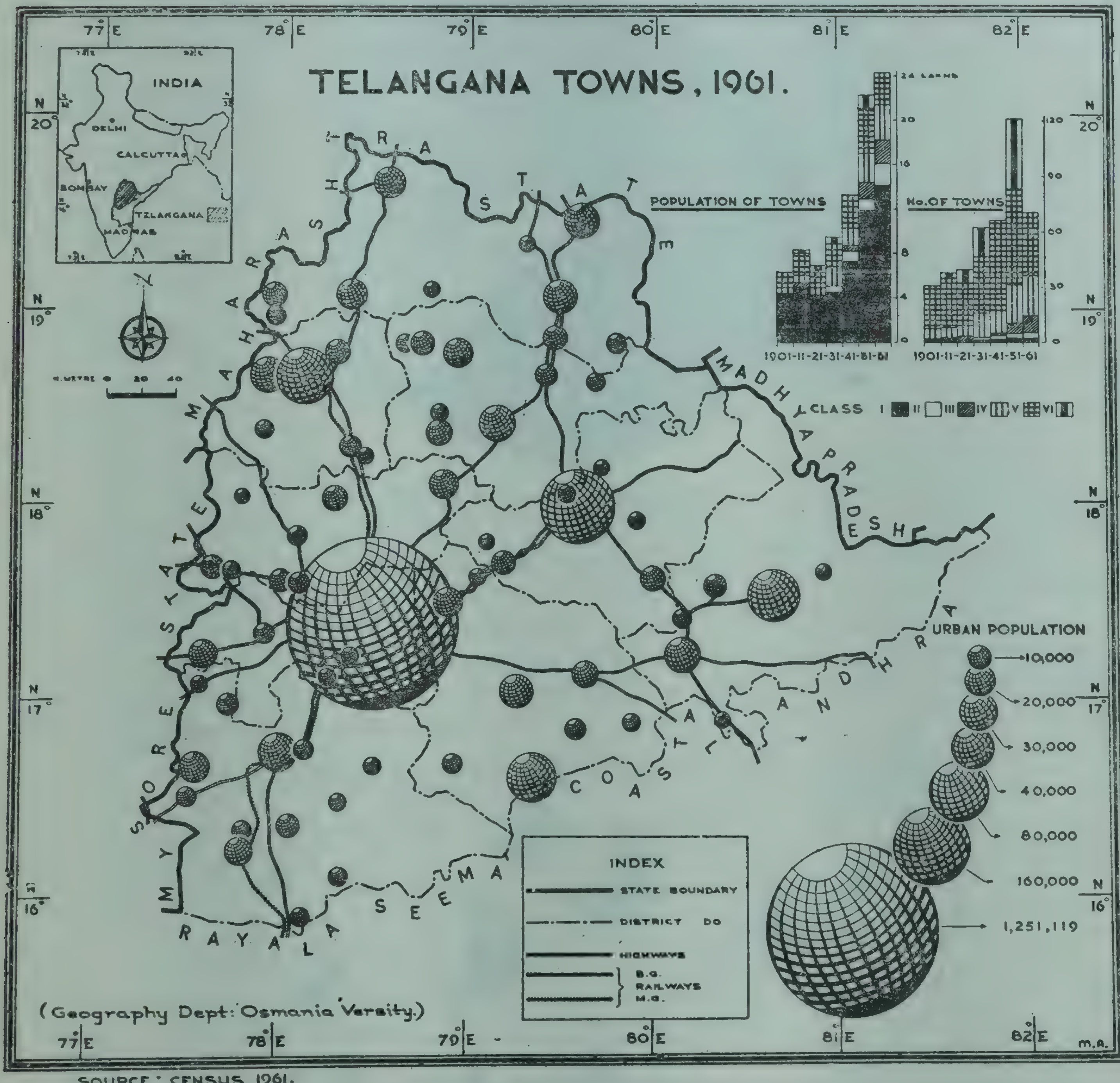


Figure 199 : Representation of quantitative data by spheres

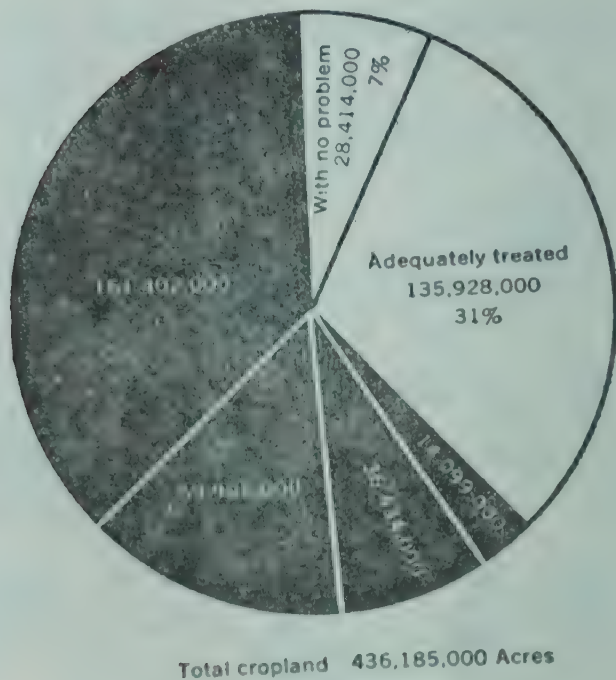


Figure 200 a : A pie-chart

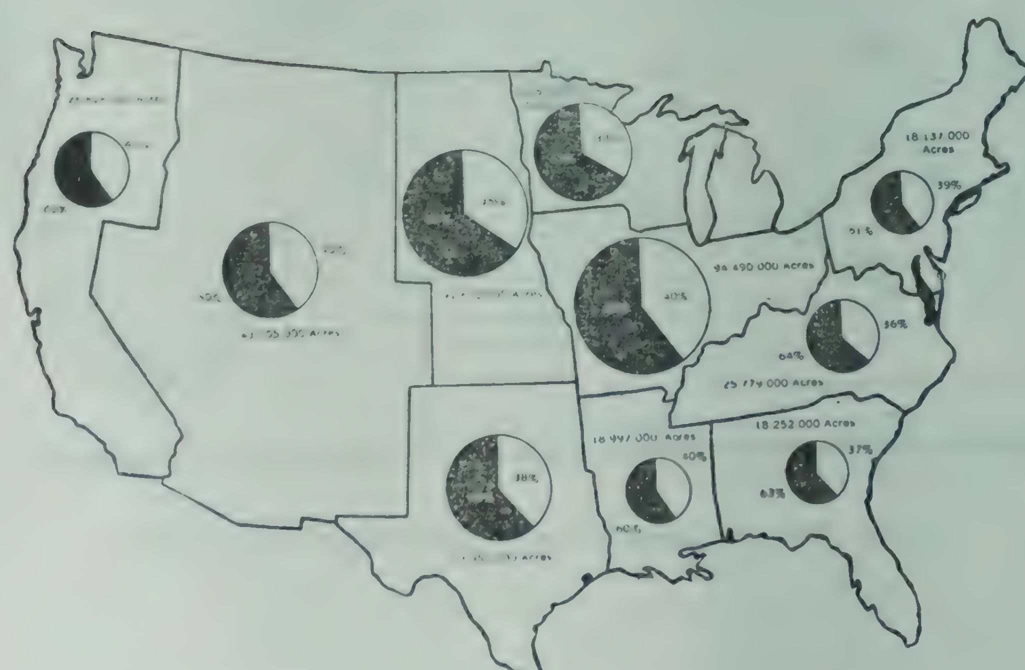


Figure 200 b : A map showing data by pie-charts

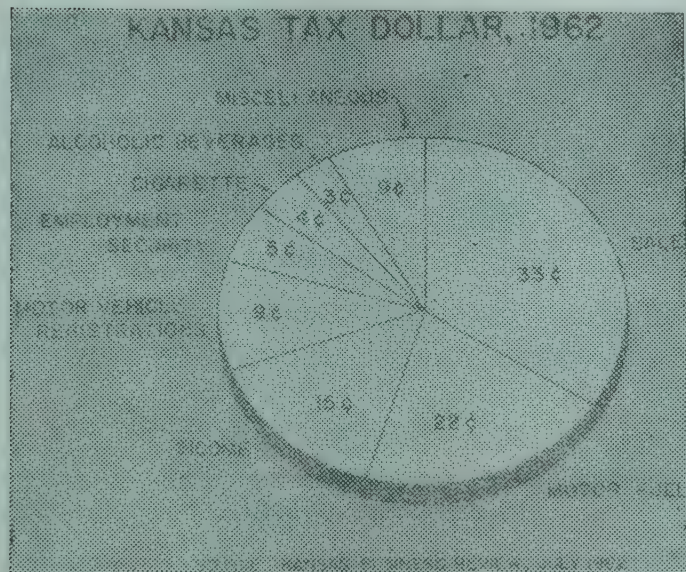


Figure 201 : A perspective pie-chart

Curve Plotting on arithmetic scale :

Curve plotting is one of the important ways of representing statistical data graphically. Although line graps are rarely used in maps their independent uses are quite frequent. They can be drawn to show temporal changes in the production or growth of one or several variables. To construct these graphs, time is given on the horizontal axis and the production or growth on the vertical axis. To give a comparative picture of change in the production or growth of more than one commodities one can draw curves for each individual commodity with a common origin as shown in Figure 202.

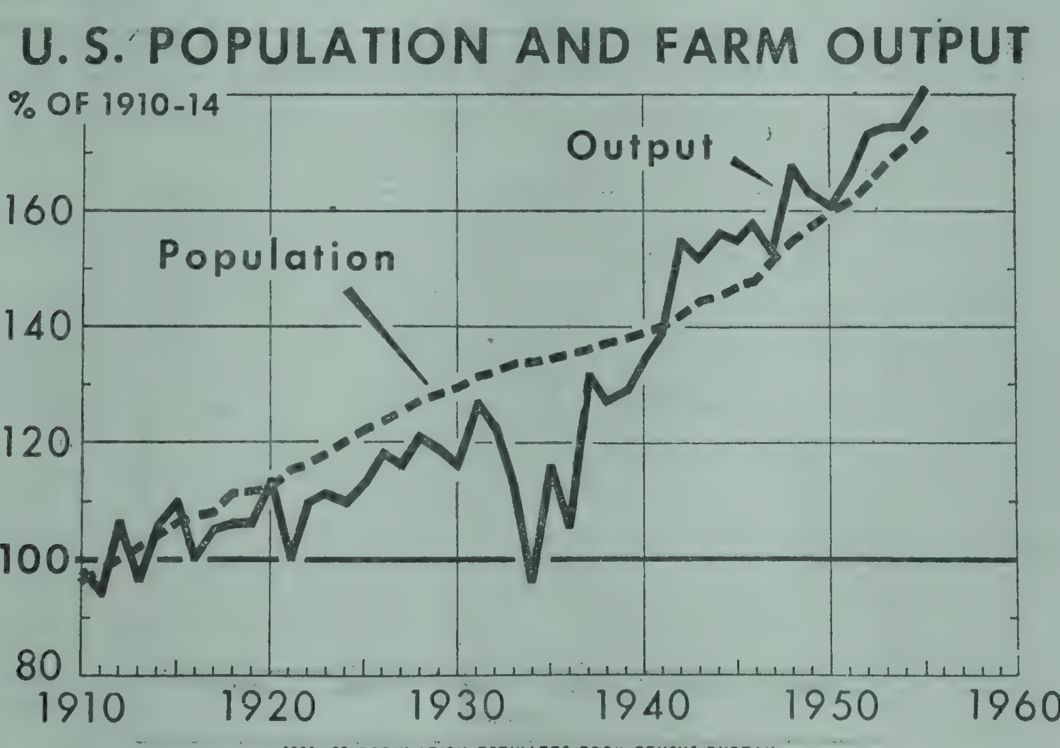


Figure 202 : U.S. population and form output represented by curves on arithmetic scale

Moving average curve :

The curves of the type illustrated in Figure 202 are marked by sharp fluctuations. To get a more generalized picture, they can be smoothened by the use of moving or cumulative averages.

To get moving average we add the figure for 2 or 3 years and divide the total by the number of years. This procedure eliminates sudden fluctuations resulting from some abnormal conditions like epidemics, famine, recession etc. Table 26 gives a three year moving average.

Table 26

Year	Average Yield per acre	Moving average (3 years)
1945	30	30
1946	70	44
1947	40	46
1948	38	50
1949	20	33
1950	100	55
1951	80	66
1952	10	63
1953	20	40
1954	70	33
1955	60	50
1956	30	53

Larger the number of years clubbed together, smoother the curve, and smoother the curve more generalized a picture one gts (Figure 203).

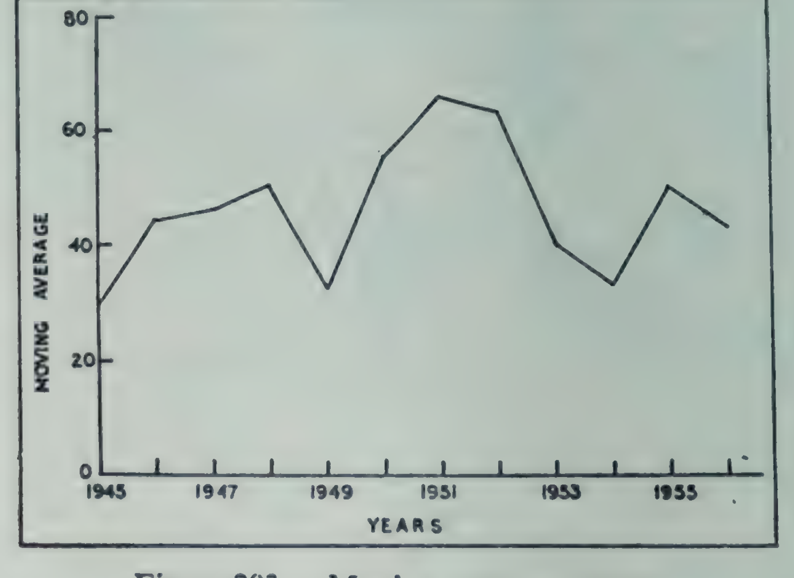


Figure 203 : Moving average curve

Cumulative average curve :

A cumulative graph is a useful device for analysing annual or monthly production or growth. It is designed to represent at each point the total of all the preceding separate items. The cumulative total and the total at the end of the period are the same (Table 27 and Figure 204).

Table 27

Year	Population increase	Cumulative average
1947	500	500
1948	300	800
1949	400	1200
1950	250	1450
1951	600	2050
1952	550	2600
1953	400	3000

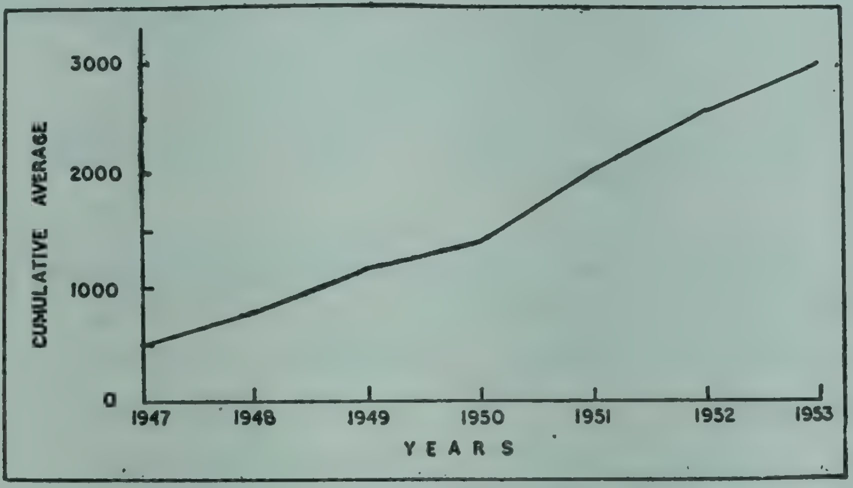


Figure 204 : Cumulative average curves

A cumulative graph can be drawn on either an arithmetic or semi-logarithmic scale.

Component part curve :

By showing total production of, say, cereals on the Y axis and the year of production on the X axis, we can depict the relative production of several commodities at different temporal stages. We may select only one commodity but different areal units for comparsion purposes. Such charts can also be made by using percentage figures. An example of such a graph is given in figure 205.

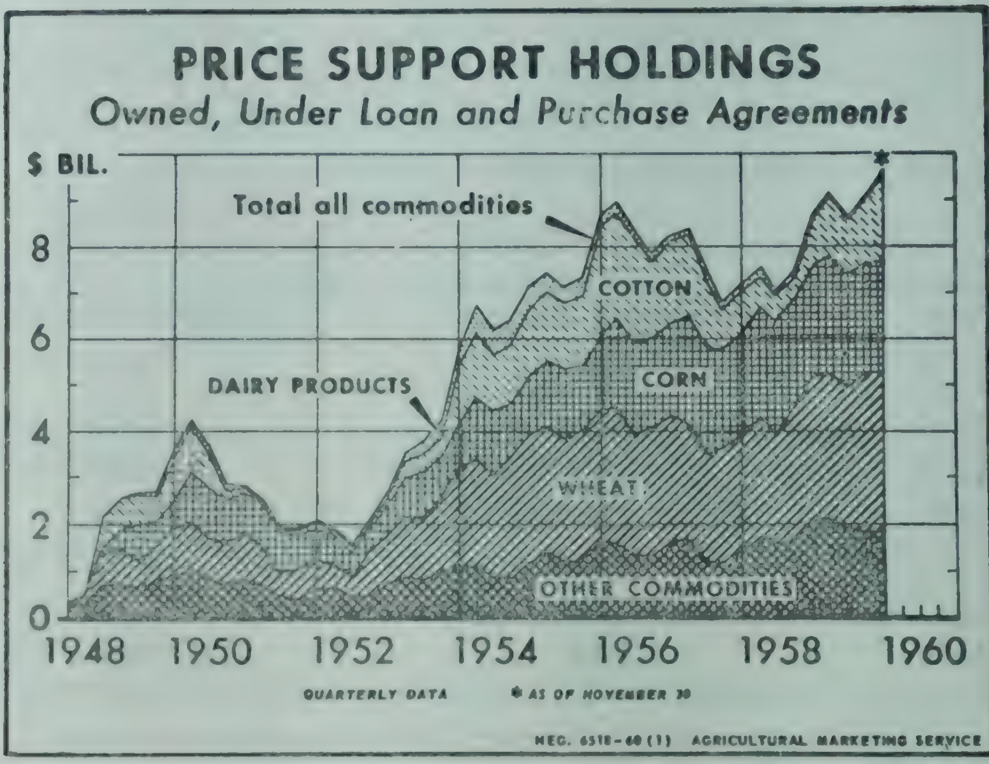


Figure 205 : Component part curve

Curve Plotting on semi-log scale :

The line graphs discussed and illustrated so far are usually drawn on arithmetic scale. Such graphs are very useful for showing absolute changes. Quite frequently we are, however, interested in depicting percentage rather than absolute changes. To do this we need either to convert the data into percentages or to devise a scale which will show the rate of change even when absolute figures are used. To convert the data into percentage is a time consuming process. Hence we often use the semi-log scale which gives the same results with absolute figures. This scale shows geometrical progression.

The vertical scale of an arithmetic chart starts with 0 whereas that of the semi-logarithmic chart starts with 1 or any other convenient number having 1, such as .0001, .01, 100, 1000, etc. As semi-log chart can be used in comparing percent changes in two series, it can also be used in comparing the relative severity of fluctuations in different series (Figure 206).

When the percentage figures are used on the arithmetic scale, we may get a straight line. The same line can be derived by using the absolute figures on a semi-logaritmic scale.

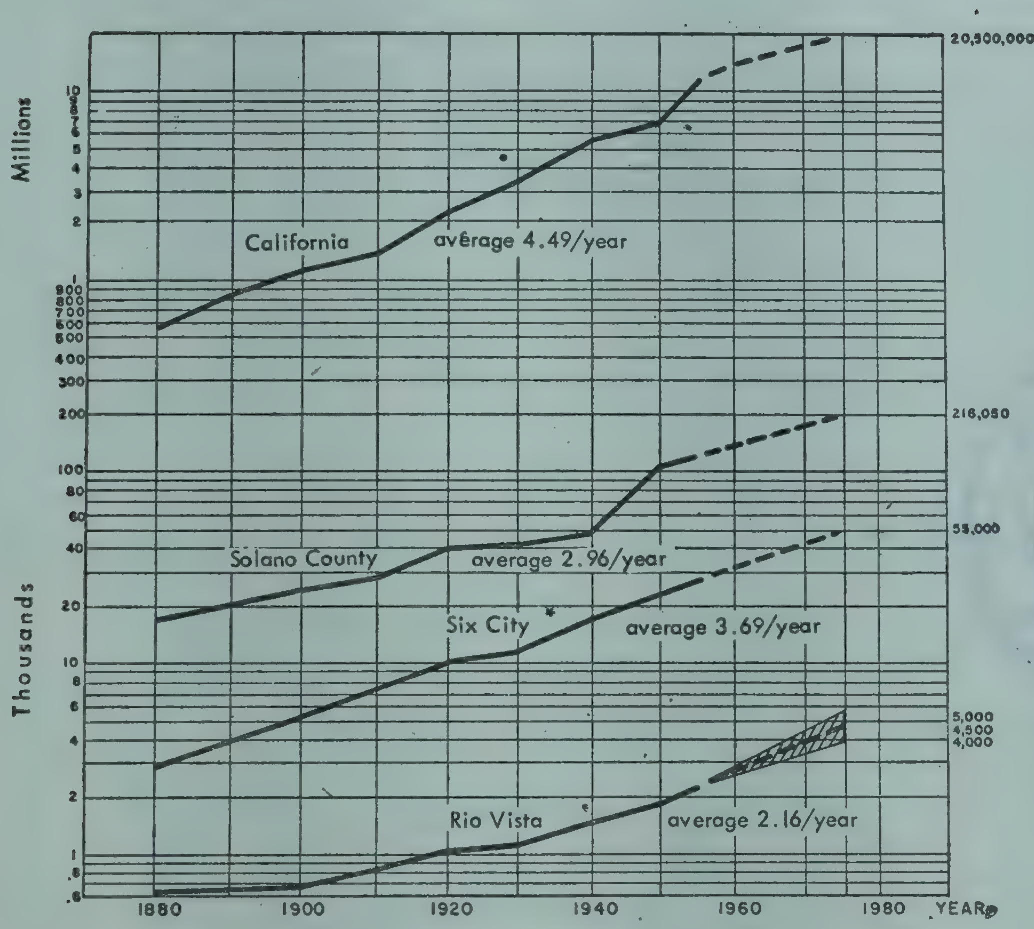


Figure 206: Curve plotting on semi-log scale. Here the curves show the population trends and projection (1880 - 1975) for Rio Vista Planning Area of Solano county, California.

Flow Charts:

The flow of goods or people can be shown by lines with or without arrows. Arrows point the direction to which the movement takes place. The thickness of the lines is determined by the volume or quantity of flow. Flow lines are often used to represent international, national or regional flow of various commodities.

Depending upon the number of directions and destinations to which the commodity moves, a flow line branches off to a number directions from the origin. As the width of the line is determined by the quantity or volume of commodity moving, when part of the commodity is diverted to a different direction, the main flowline also becomes thinner proportionately. When two flow lines cut each other, some space is left along the one to keep the two distinct from each other. Examples of flow charts are given in Figure 207.

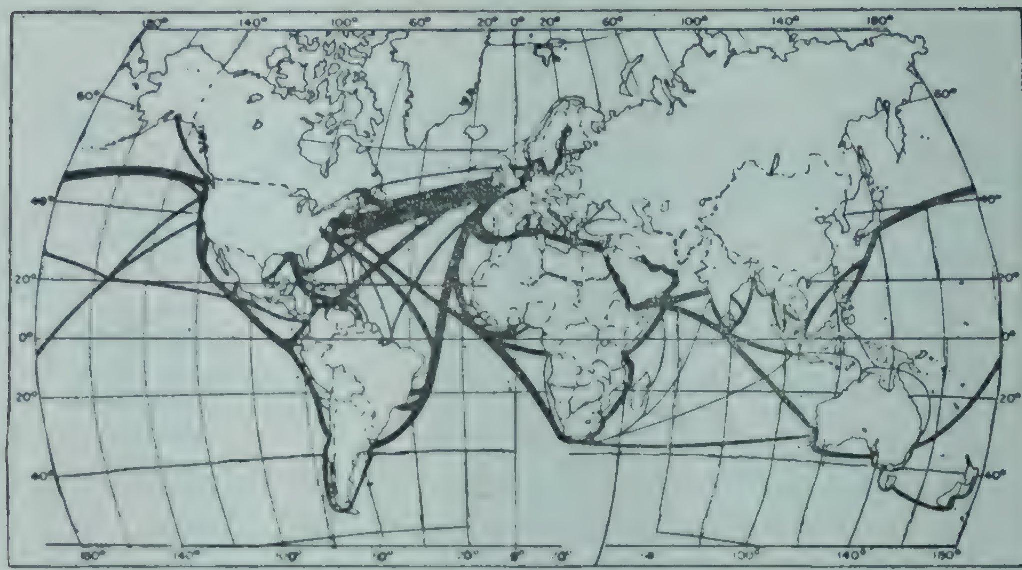


Figure 207 a : Flow line charts : World consumers and commodity demands,

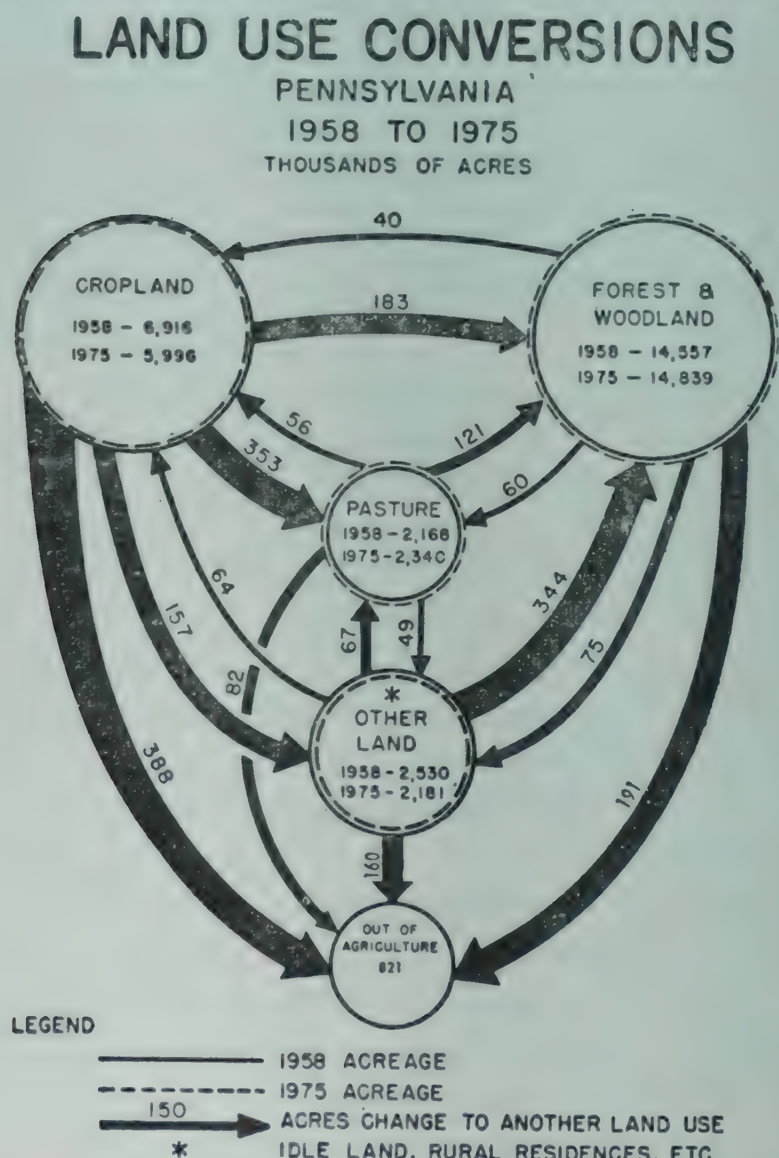


Figure 207 b : Flow line charts : Land use conversion in Pennsylvania, 1958-1975.

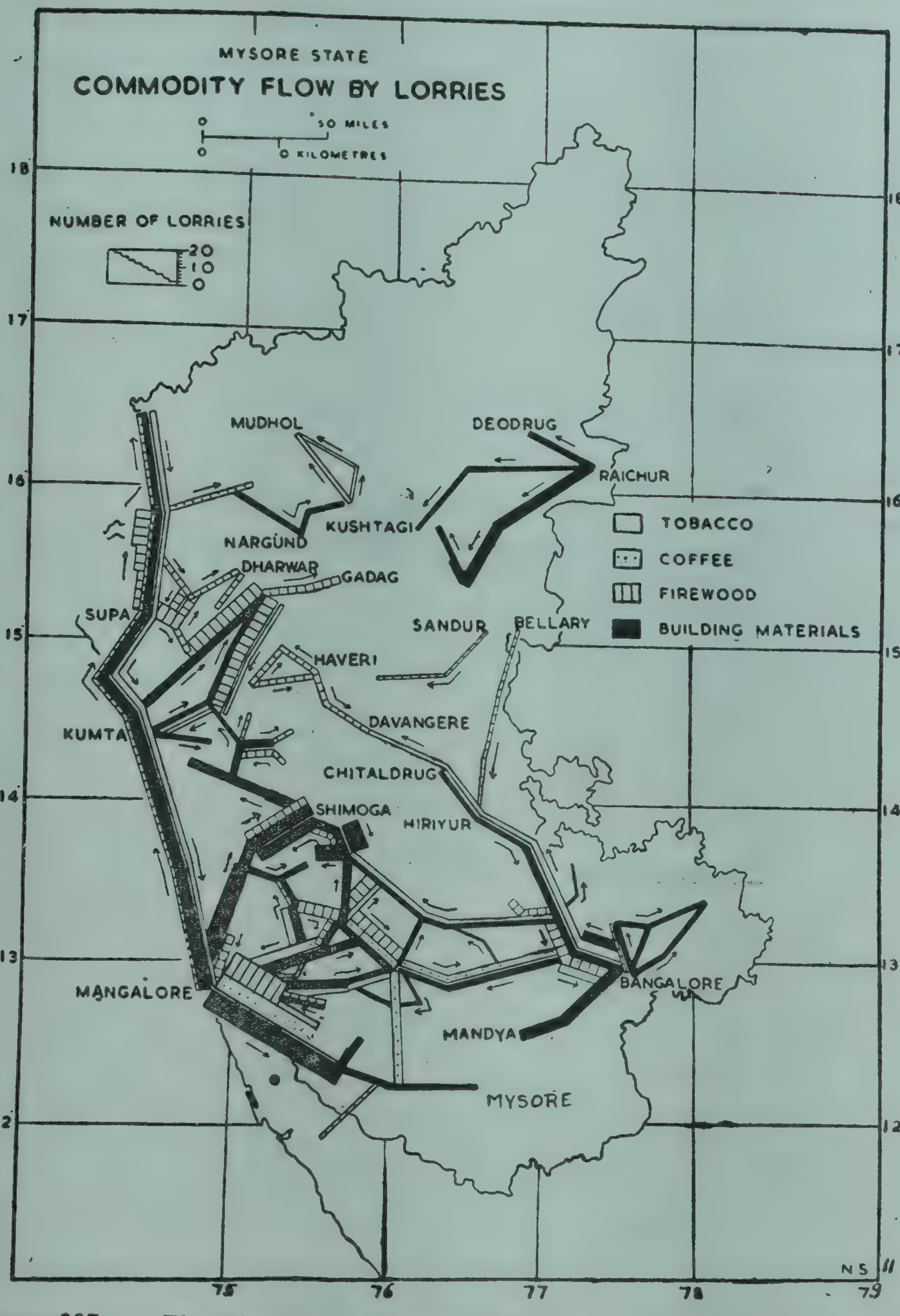


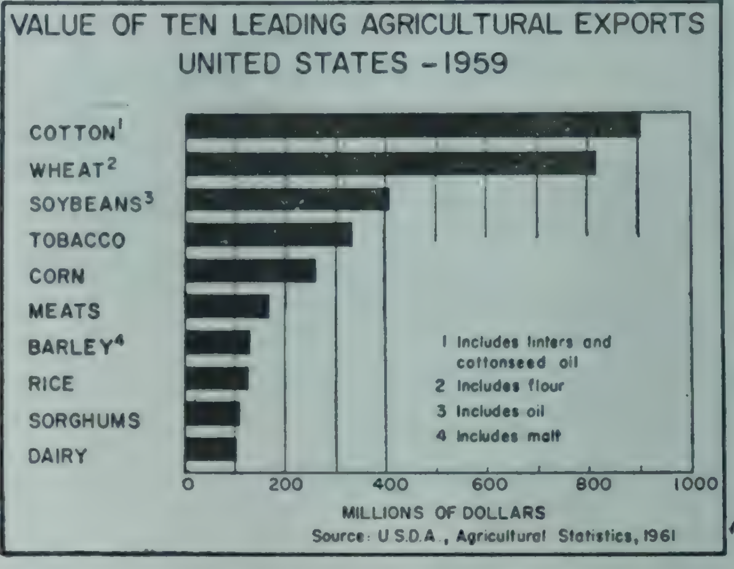
Figure 207 c : Flow line charts : Commodity flow by lorries in Mysore state

Bar Graphs :

The representation of volumes or quantities by bars is easy and simple. Bars can be placed vertically or horizontally. The length varies in proportion to the quantity represented. There are two types of bar graphs : (1) simple and (2) complex. The simple bars have no subdivisions, so that each bar represents one commodity for a given period or place. In this type of

graph, only the length of the bar changes proportionately but the width remains constant. (Figure 208). The data can also be converted into percentages to prepare bar diagrams. Bar diagrams showing temporal variation can also be made.

Further complexities can be brought in by showing more than one commodity production at different places. Another version of the bar graph is the divided rectangle or horizontal bar. The full length of the bar represents the total value. The bar is then divided into segments to show further details. For example, total land under crops can be shown by a horizontal bar, then the land under various uses can be shown by divisions.



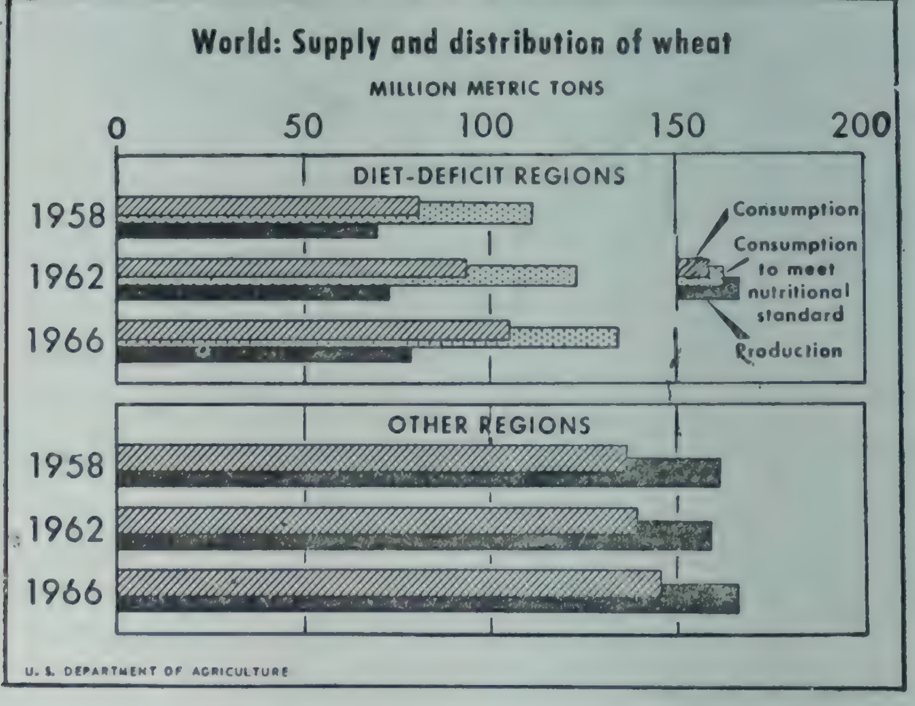


Figure 208 : Examples of simple, bar diagrams.

A number of rectangles can be drawn to provide comparisons through time. They are known as compound pyramids. Such graphs can also be used to show sex and age ratios etc. Here they are known as age and sex pyramids (Figure 209).

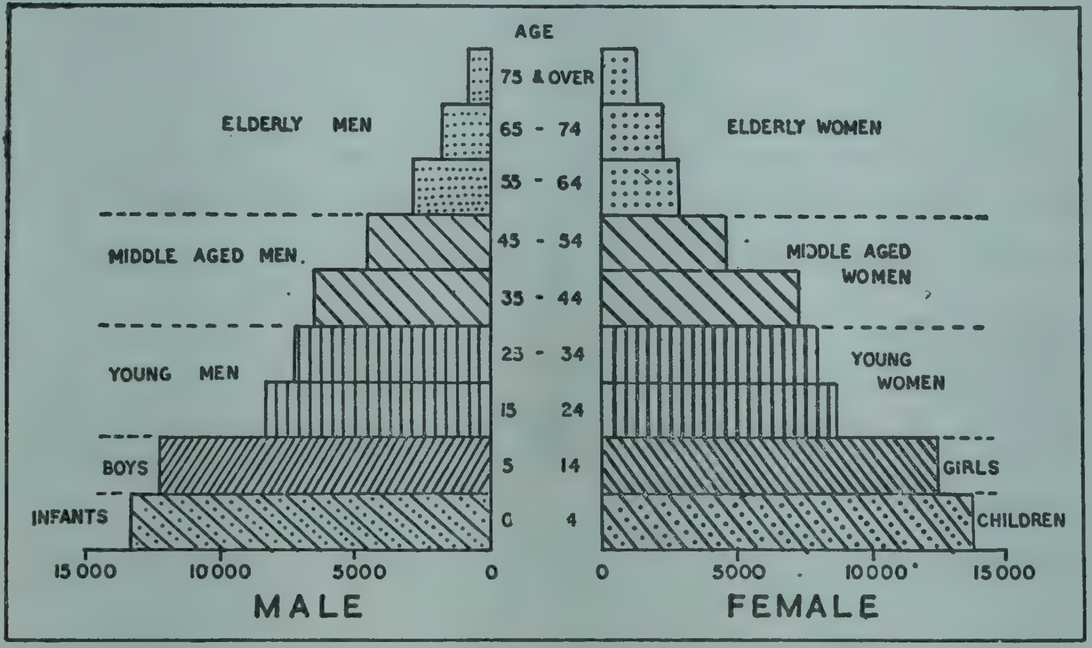


Figure 209 : An example of an age and sex pyramid

All these bar graphs can very well be superimposed on maps to give suitable cartograms.

Isochrones :

Isochrones connect places which takes the same amount of time to reach from a given centre. We know that geographic distance is different from time–distance. When places are connected with each other by modern means of transportation, it takes less time to go from one place to another. But in areas where the means of transportation and communication are still in a primitive stage of development, it takes lot of time to go from one place to another. (Figure 210)

Ray diagrams :

Ray diagrams are used to illustrate the spheres of influence of towns etc. The affinities between the urban centres and the villages in the surrounding countryside can be indicated by simple lines radiating from urban centres. Such diagrams can also be used to show the relative importance of various functions of a town. Often, these are called wind rose diagrams. (Figure 211).

Block pile diagram :

This method involves the piling up of a number of cubicals one above the other in such a way that each one of them can be easily counted. Being three dimensional, one of its sides is shaded so that it gives a perspective view. It is relatively easy to make. All that is needed is to assume a small unit cube to represent a given quantity. Such unit cubes are then piled one above the other to produce a block. One of the sides of the block is sub-divided into 10 equal parts to represent sub-divisions. (Figure 212).

This diagram gives an impressive visual result. The values represented by a block pile diagram can be easily counted and understood. It occupies less space than a circle but more than a sphere.

Figure 210 : Isochrones showing the number of hours required to reach various parts of India from Delhi by the fastest available train, in 1958

Choropleth, dasymetric and isarithmic maps :

"Geographical quantities which exist over an area exist in vast array and range from the simple to complex, including many very useful abstractions". It is due to this fact, that a cartographer faces a serious problem in their representation. Geographic variables are of two types (1) discrete, and (2) continuous. The real difference between the two is more theoretical than practical because one can easily be converted into the other. Let us have an example. We know that the population distribution is not a continuous

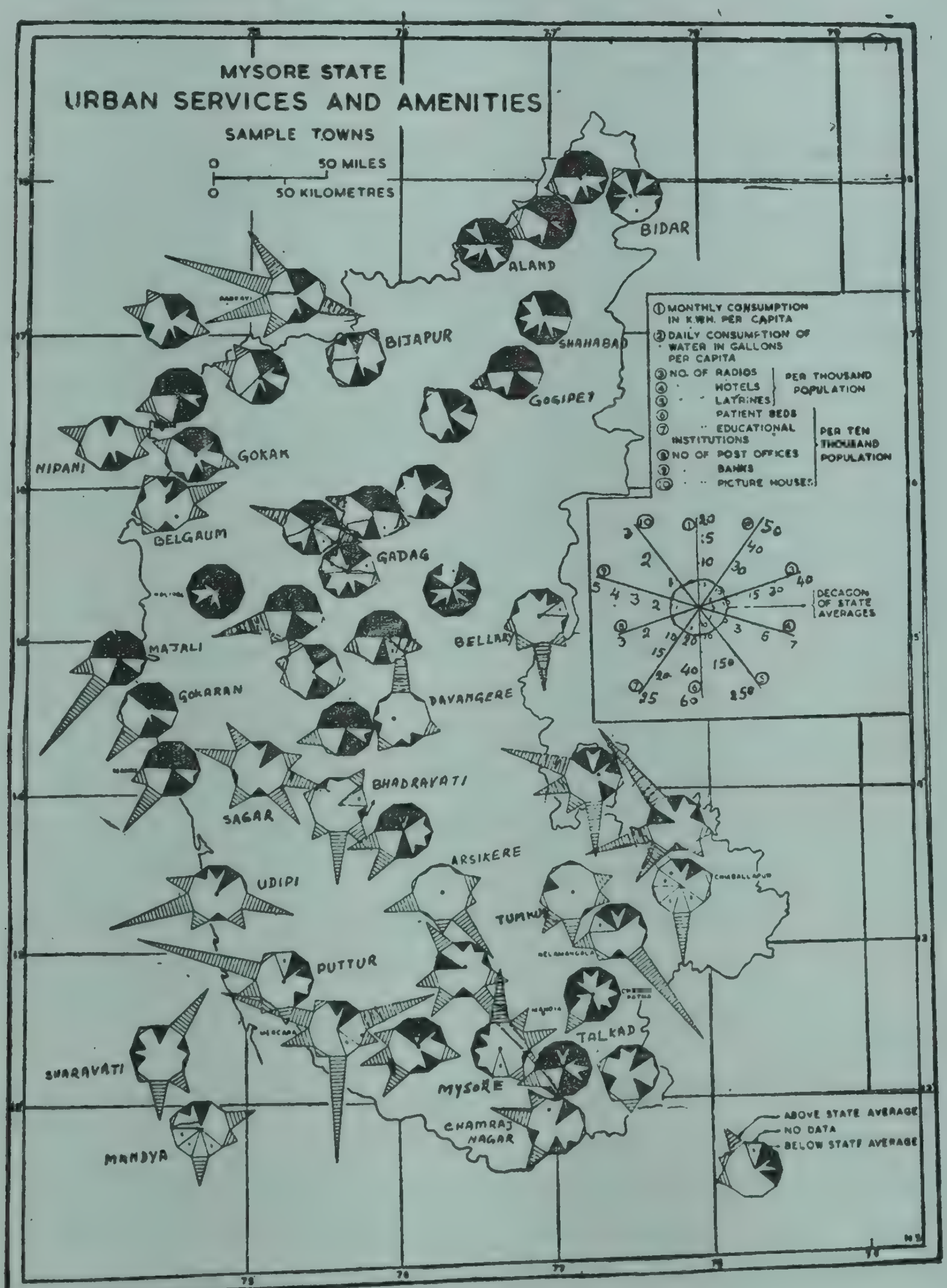


Figure 211 : Ray-diagram showing urban services and amenities in Mysore State.

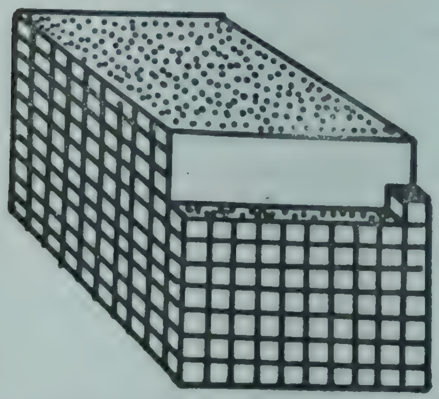


Figure 212 : Block-pile diagram

phenomenon. People live in clusters. We collect information about each of these clusters and then divide the total population by the area of an administrative or other unit to get the density per sq. mile or kilometer. We know that density is a continuous phenomenon, but not the distribution of population which provides the data for calculating density. Here we have converted discrete data into continuous data. The total population of an area can be shown by a column built at a central position to show the total population of each administrative unit. In doing so we have to convert the spatially dispersed data into discrete data, for we assume that the total population of the area is located at one centre.

Because of the possibility of converting continuous data into discrete data and *vice versa*, we are able to show the distribution of various phenomena either by density patterns or by point symbols. In the former case, we use density figures whereas in the latter, we use absolute figures. We may yet find a set of data which show neither of these characteristics. We saw that in continuous series the densities are calculated with respect to the areal unit selected for the purpose. In one unit the density may be high and in the other quite low. The boundary between the two units will mark a sharp break in the density patterns. But we know that many of the phenomena do not respect man-made boundaries. To solve this problem we can do one of the following two things.

1. We can generalize the area densities to do away with administrative boundaries, or
2. We can treat the given data as continuous and further generalize them to give step-like isarithmic lines.

If we follow the administrative boundaries to show densities by line or colour patterns we get a choropleth map. When we generalize this

choropleth map, we get dasymetric representation. But when we further generalize the data and use isarithmic lines, we get an isarithmic map. (Figure 213).

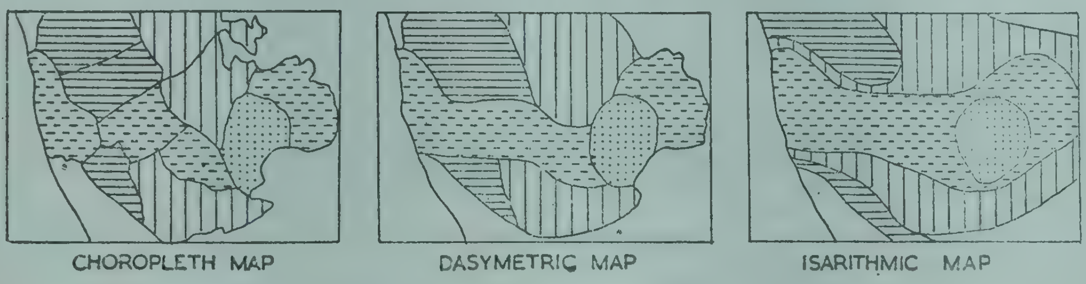


Figure 213 : Choropleth, dasymetric and isarithmic maps

Among the three the choropleth method is the most commonly used method. The simplest of the choropleth maps is the one which shows the density per square unit of area at a given level of civil divisions. If the total population of a civil division of 10 sq. miles is 1000, its density is 100 persons per square mile. This way we can calculate the density for each of the civil divisions to get a choropleth map as shown in Figure 213.

Choropleth maps can also be constructed to represent the deviation of the data from its average. For example, the density of a country as whole can be taken as the mean and the deviation of regional densities from this mean can be represented to give an idea of the density anomalies. Such maps can be prepared to show a variety of facts like production, age group distribution and so on.

Choropleth maps are drawn to represent certain changes also. This can be done in two ways. Suppose we want to show changes in the density of population between 1951 and 1961. We can draw two choropleth maps showing distribution in 1951 and 1961. The other way of doing it, is to calculate the index of change. This can be done by dividing the area total for 1961 by the area total for 1951.

Pictograms or Pictographs :

Statistical data can also be represented by such pictorial symbols like sacks, bales, coins, human or animal figures etc. (Figure 214). For example, to show the distribution of human being in the world, we can show human figures. The number of figures will depend upon the data to be represented and the scale of the map. Such maps are very good illustrative materials for classroom purposes.

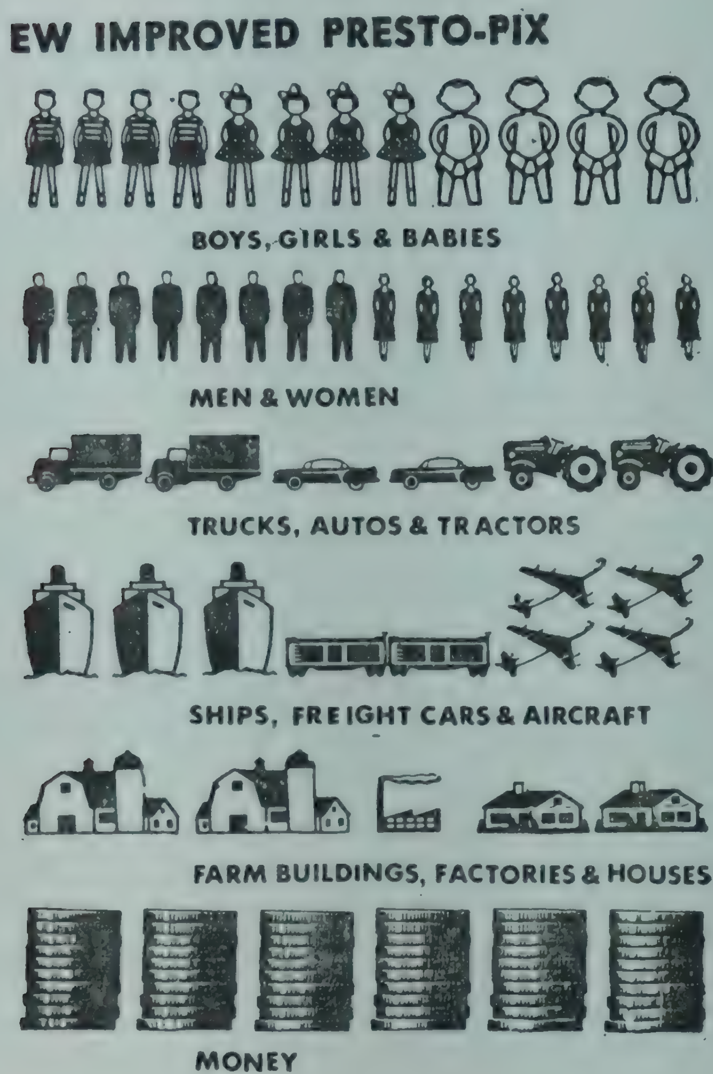


Figure 214: Pictorial symbols.

CHAPTER XXI

THEMATIC AND COMPLEX MAPPING

THEMATIC MAPPING

If we rely on semantics, any map which has a theme to offer, can be said to be thematic. Such a broad view, however, leads us nowhere because there is no map which is without a theme. What we really mean by thematic map, is a map which specialises in portraying a specific information without caring for the other, often more important but irrelevent to basic theme, information. The purpose of such a map is not to cater to the needs of the general map user but to meet the requirements of the specialists who deal with the particular type of information portrayed in the map.

To make the distinction between a thematic and a general purpose map more clear, let us take the example of a soil map of India and a 1:1000,000 sheet of Survey of India. We will find that in the 1 : 1 million sheet we get all those topographical detatils which can be incorporated in the sheet. If there are details which have not been represented on the sheet, it is because they were too small for the scale of the map and not because they were deliberately suppressed. Such maps are useful to all, specialist as well as common man. But the soil map tells quite a different story. It gives in permissible details everything about the distribution of various types of soils of the country but does not care to deal with all the details depicted on the 1 : 1 million sheet of the Survey of India. Such a map is useful only to those who are interested in soils such as pedologists, land use planners and farmers. The soil map is a thematic map whereas the 1 : 1 million sheet is a general purpose map.

There is another distinction that becomes obvious as soon as we see the two maps referred to above. The million sheet of the Survey of India is constructed on a much larger scale than the soil map of India.

Most thematic maps are found to be drawn on smaller scales but this should not be treated as a rule. In fact, many of the thematic maps of the National Atlas of India (English Edition) are drawn on a million scale. But that must be the largest scale, possible for a country like India. Small countries with smaller territories can afford to make thematic maps on still larger scales. Nevertheless most thematic maps are drawn on much smaller scales than the topographic sheets. We can therefore say that, by and large, thematic mapping is essentially a function of small-scale cartography. Sometimes thematic maps are called statistical maps and *vice versa* These two terms are not interchangeable, although most thematic maps do use data derived from statistical manipulation of the raw data.

There are two types of thematic maps: (1) simple thematic maps are those which concentrate on the representation of a single feature; and (2) complex thematic maps are those which represent combinations, correlation, association, variation or interconnections between several aspects of the same phenomenon or between two or more phenomena. An example of the first type is a soil map giving the distribution of various types of soils in a given area (Figure 215). An example of the second type is a map showing the association or correlation between rainfall and rainfall variability (Figure 216).

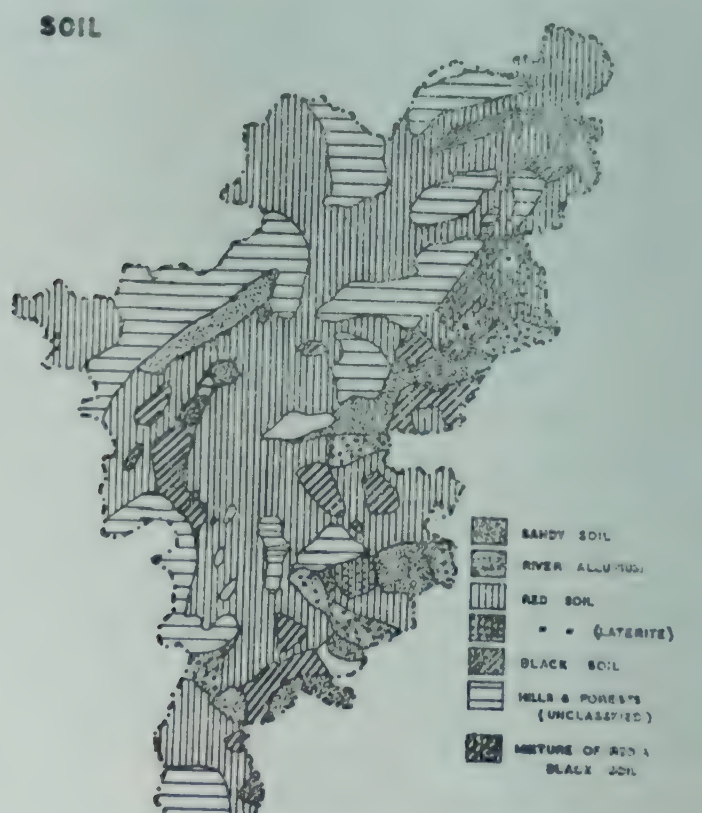


Figure 215 : A qualitative thematic map (Soil map of Tamilnad)

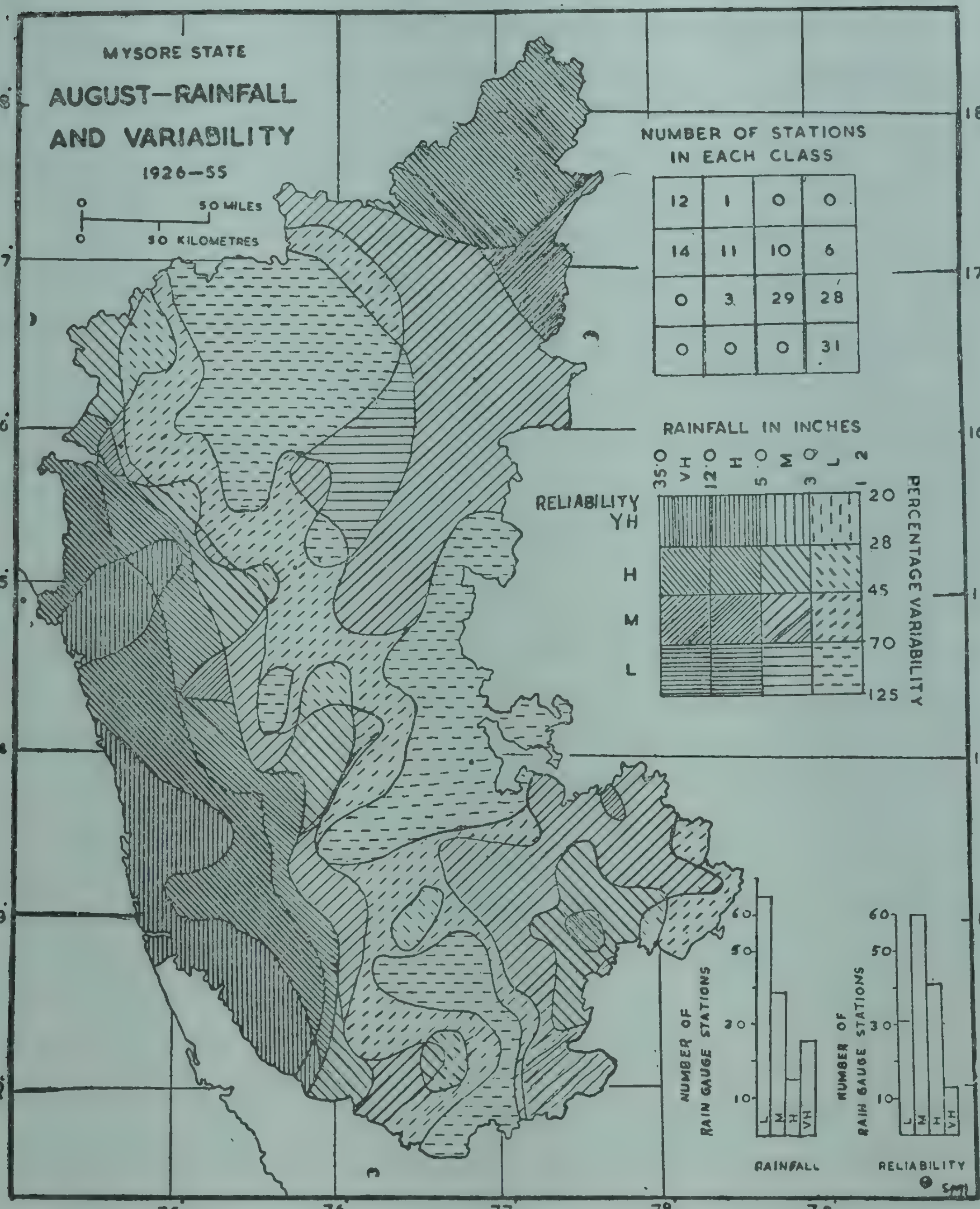


Figure 216: A complex thematic map: Ranifall and its variability in Mysore state (Learmonth)

SIMPLE THEMATIC MAPS

Simple thematic maps can be classified into three types:

1. Qualitative in construction as well as in appearance.
2. Quantitative in construction but qualitative in appearance.
3. Quantitative in construction as well as in appearance.

Qualitative Maps:

These maps show such natural and cultural features, the distribution of which is usually not measured quantitatively. Among such features are lithology, rock types, soils, vegetation, religion, language and so on. It is not to suggest that such features and their various aspects are not quantifiable. What is suggested is that the non-quantitative aspect of such features are quite important and hence are often represented on maps.

One of the great difficulties in the construction of qualitative thematic maps is the problem of mixed or transitional areas. If we are showing religion-wise distribution of population in India, the Hindus are in majority in almost every administrative unit. How can we show the distribution of minority groups like Christians, Moslems and Sikhs, unless we base our maps on certain quantitative values. There are, of course, methods to deal with such problems, but they give only a schematic picture.

Most of the qualitative maps use colour patch or chorochromatic method of representation. Colours are chosen carefully so that they do not clash and are distinct from each other. Similar features have similar colours. For example, in a geologic map, all tertiary formations are shown in one colour. Similarly in a historical map, the areas falling within different kingdoms or countries are shown by different colours.

Qualitative thematic maps may also show the distribution of such features which do not have areal extension. For example, a railway map shows the railway lines with line symbols. If these lines have different gauges or zones, each gauge or zone is shown by a different colour or line symbol. At times a qualitative map gives only locational data. For example, a mineral map may be constructed to give the location of mines of various fuels and minerals without giving anything about their size or production. All such maps are thematic but non-quantitative. The reader should, therefore, be careful in not equating a thematic map with a statistical map. The two are not always the same.

Semi-quantitative maps:

There are a number of techniques of cartographic representation which are qualitative and quantitative at the same time. The most glaring example of this is the dot map showing the distribution of population or slope. In a dot map, each dot represents a quantitative value but we rarely use it for quantitative interpretation. It gives only a visual picture of distribution ; we never try to get the values represented by the dots by multiplying the number of dots by the values assigned to each dot. A dot map is different from a

choropleth map. By looking into the legend of a choropleth map we can determine the density of the element represented. But a dot map does not help us to do that. Each dot stands individually and at least theoretically, stands for the point at which it is placed. It represents no area and hence gives no quantitative measurement.

Quantitative Maps :

Finally we come to the simple thematic maps of quantitative nature. Among such maps are the density maps which give the frequency of occurrence of a phenomenon by civic divisions such as Taluks, Tahsils, Districts or States. The simple way to prepare a distribution map is to colour or tint the civil divisions darker or lighter in proportion to the density of distribution.

We can have choropleth or isopleth maps also to represent distribution. Such maps give the numerical values for different areas. We use isopleths for continuous areal distribution and choropleth for discrete areal distribution.

COMPLEX THEMATIC MAP

When more than one set of equally important data are portrayed on a single map to show combination, correlation, association, or interaction, we get complex thematic maps. Almost all complex thematic maps can be called quantitative maps. Such maps may show, for example, the rural and urban population by circle graphs. In a medical map disease morbidity, death rate, number of hospital-beds and so on, can be shown on a single map to give a comparative picture. Most of these maps are analytical and give very specialized type of information.

PROBLEMS IN THEMATIC MAPPING

Data and their representation:

Whether simple or complex, a thematic map is designed to give a limited information. It caters to the specialized needs of the people. The idea is to represent something which will appear more prominent than the other possible details. For example, if the purpose is to show the distribution of cattle, nothing should appear on the map as prominently as the distribution of cattle.

What other data should be shown in a thematic map? Should we show the physical built of the country? Should we show the river valleys, mountains, rainfall and other pertinent data also? If we decide to do so, then the question arises as to whether we should have a single map or or a series of maps. If we give the distribution of cattle by dot method and show the pertinent

physical details in the background, we get a simple thematic map. The population sheets of the National Atlas of India fall in this category. But if we venture to show the relationship between, say, rainfall and density of cattle, then we get a complex thematic map. In the latter case the objective is to show the relationship between two phenomena and not to represent the distribution of a single phenomenon.

If we are making a simple thematic map, we have to keep the less important but not irrelevant data in the background. We know that the distribution of cattle will depend upon a variety of factors. Some of them are physical while others are cultural. Among the physical factors are the landform, climate and vegetation. In a hot and wet climate cattle do not thrive well. In areas of scant vegetation and sparse settlement, one does not find many cattle. In many mountainous areas too cattle are not important. In arid areas, one finds sheep instead of cattle. How to show these facts on a map showing the distribution of cattle is one of the important problems in thematic mapping ?

If the purpose of the map is to show the distribution of cattle, no other data should be shown as prominently as this. We can show the landforms by light plastic shading, rivers in light blue and temperature by lightly coloured isothems so that a map reader interested in knowing the reasons why cattle population is thin or dense in certain areas, can speculate the possible reasons by interpreting the background information.

Selection of Map Projections:

All map projections, as we have already noted, do not suit the requirements of all types of representation. Maps showing the areal distribution of a phenomenon must be drawn on equal area projection. But there is no equal area projection which shows every part of the world satisfactorily. On the margins the shapes are so distorted that the representation reaches the stage of meaninglessness. With the increasing tempo of international cooperation, necessity of thematic maps with common scale, projection and symbols has not only increased but also become indispensable. Further, the variety of thematic maps that we see today and which are in the offing, are so bewildering that limited number of simple projections that we have at our disposal will not suffice. As each thematic map is unique in many respects, it may need a unique projection suited to it and, may be, it alone. We have, therefore, to devise new ways of deriving projections and to elaborate and develop further the already known projections to suit modern needs.

In this regard Tobler in the USA has done considerable work. He has not only given lead in the derivation of projections by feeding the data to the

computers, but also in newer uses of projections. Projections, he says, are nothing but the means to transform a given surface into some other form. This concept, although inherent in map projection had not caught the attention of geographers. If transformation of a surface is the real purpose behind map projections, the conventions regarding the location of poles, equator and parallels and meridians has no meaning. The approach has opened up new avenues for research in this area.

Choice of base maps :

The success of a thematic map depends to a considerable extent on the quality of the base map. As the demand for thematic maps increases the need for devising more efficient ways of preparing base maps will certainly increase. Even at present, thematic cartographers are handicapped by the non-standardised base maps available to them. Specially for the purposes of International Series of thematic maps, the quality and uniformity of base maps need further improvement.

Generalization of data:

This problem has already been discussed in the chapter dealing with map compilation. But even at the risk of repetition, it is necessary to discuss this problem here. Thematic mapping being essentially a small scale mapping, the problem of generalization is more pertinent to this aspect of cartography than to others. At present we have no standard method of generalization. In fact each cartographer uses his own intuitive judgement in this regard rendering the comparison of maps produced by different organisations difficult.

The problem of generalization acquires new complexities in case of thematic cartography, especially because thematic maps are drawn on varied scales, and each scale can take only so much of generalization. The time has, therefore, come when the theory of generalization is elaborated and further refined, so that the intuitive approach is replaced by ' standard measures '.

Standardisation of symbols :

So long as each country considered itself to be an island for cartographic purposes, the problem of standardization of symbols did not arise. With increasing contacts among the nations of the world, many of the topographic symbols have been given international standards. But not much has been done to standardise the symbols used in thematic mapping. For the efficient estimation, comparison and use of our resources, it is necessary that thematic maps showing a given information but representing different

areas of the world, use same symbols. This is now equally true for national maps. The International Geographical Union has recommended a set of symbols to be used by all the member countries engaged in landuse mapping. If landuse maps using these symbols are prepared by each country, it will be possible for us to determine and compare the land resources available in different parts of the world more precisely. Unfortunately not all the countries have accepted or implemented the recommendations of the I. G. U.

Compilation of data :

Compilation problems have been discussed in detail at the appropriate place in this book. Here an attempt is made to emphasize how this aspect of thematic cartography has now acquired added urgency. As the number of map users increases, and the opportunities to further refine and analyse the data improve, more and more of specialized maps will be needed. The existing process of compilation is slow and cumbersome and more suited to the days when maps were the properties of a privileged group. Methods which give results quickly and also cheaply will have to be adopted. The mechanical process of compilation involving the use of computer and its accessaries appears to show the direction in which cartographer should move for this purpose.

Design of maps :

The data which thematic cartography is destined to use are going to be far more complex than those used presently. Yet simplicity and legibility are the standards by which maps are and will continue to be judged. The map design of today would not suit more complex data of tomorrow. To develop new designs to suit newer needs of ever increasing number of disciplines, needs concerted efforts to train the cartographers in both the artistic and scientific aspects of cartography. There is a definite need for such centres in each of the major map-producing countries which will conduct fundamental as well as applied research in map design and will give advanced level training to professional cartographers and specialized training to subject specialists interested in mapping and graphics.

Reproduction of maps :

Mass production of maps is going to be one of the basic problems of thematic cartography. Mass production means not only production in large quantity but also production at a cost which is within the reach of average map user and production at a speed which will keep the map

as less obsolete as possible. All maps become obsolete even before they are produced because the world they represent is dynamic and ever changing. But those maps which take years to come out of the press, are surely more obsolete than those which come within a week. The modern map user insists on getting as up-to-date information as humanly possible. Unless methods are devised which can reproduce complex and multicolour maps quickly and cheaply, thematic cartography will not be able to catch up with the needs of the time.

Inter-disciplinary coordination:

Thematic cartography is dualistic in essence. Its various branches — geological, pedological, geobotanical, population, economic, space, etc — belong to cartography by method and techniques, and to sister sciences — geology, pedology, geobotany, demography etc.—by contents, Cartography being the study of spatial distribution, combinations and inter-dependencies between nature and society and of their changes through time, with the method of representation and by means of symbols of its own, it can have as many branches as there are disciplines. As new disciplines emerge out of the old ones, new branches of thematic cartography will take shape. The latest to emerge is perhaps the space cartography with emphasis on the representation of the Lunar Surface.

The development of thematic cartography has a long history, although it came to be recognized only recently. The demand for thematic maps has come from specialized disciplines like geology, pedology, geo-botany and meteorology to name a few. The users of such maps are also the specialists engaged in teaching, research and management. Obviously then, thematic cartography owes as much to these specialists as to its own practitioners for its development and growth. And if thematic cartography has to continue to develop and to cater to the needs of the ever increasing variety of specialists—ways and means must be found to bring the cartographer and other academic experts together.

The desired cooperation between various subject specialists and cartographers for the purposes of map design and construction is not peculiar to cartography. Such features are inherent in modern science in general. Today scientific research has assumed a collective character. Scientists of most diverse specialities combine their efforts to solve complex problems. Such tendencies of present day science are most favourable to the development of thematic cartography. Any discipline that is concerned with measurement and spatial processes inevitably includes the thematic map as a possible tool of

scientific research and needs the collaboration of professional cartographers to achieve its objectives.

None can expect cartographers to be acquainted with each discipline fully enough to understand its requirements. The cartographer's role in dealing with thematic maps is more of the nature of designer and engineer. The needs are to be explained by the specialists, the cartographer's function is to suggest the design which will suit the needs of the specialists best. This requires the strengthening of the fundamental concepts and techniques of cartography itself and the development of newer ways and means of solving newer problems posed before cartographers. All these can be achieved only by further research in the fields of thematic cartography and by enlisting the cooperation of other specialists.

International Cooperation:

Progress of thematic cartography is as much dependent on the cooperation between cartographers and subject specialists, as among cartographers of different nationalities. Many of the human problems are now being tackled at the international level. Important among these are population, resource inventory and development and human welfare. The cartographic techniques, symbols and concepts can no more be treated as unique features of the national cartographic centres. We have to have international standards, cutting across national standards, to be able to help international agencies in tackling the above mentioned problems successfully.

Some measure of success has already been achieved in the field of land-use mapping, geo-botanic mapping, and soil mapping. There are many more fields which are awaiting similar efforts.

International cooperation in the field of thematic cartography is as difficult as in any other field. The recommendations of the international organizations like International Geographical Union and International Cartographic Association are not binding on the member countries. Moreover, the lack of funds and also the official apathy often come in the way of undertaking the cartographic work recommended by the international agencies, Many of the recommendations therefore remain unimplemented.

Others :

The making of topographic maps is the function and concern of national cartographic services like survey of India. Such maps constitute the basic data for the preparation of other specialized maps. The enlargement of their scales, their adaptation to life's new requirements and to new ways of producing maps and their revision to keep track with fast changing surface of the earth,

necessitate continuous, systematic and scientific work. "Regular scientific research and thoughtful ideas are needed to ensure the development and introduction of new technology, the increasing effectiveness and expansion of production, the raising of labour productivity, and the cutting of production costs and the improvement of map quality.

The prospects and problems of thematic and complex mapping are far more complex and their scope almost boundless. One is led to such a view because the subject of cartography, as noted earlier, is the study of spatial distribution combinations and interdependencies between nature and society (and of their changes in time), with the method of representation and by means of a particular sign system–cartographic symbols.

ATLAS MAPPING

Atlas cartography like thematic cartography, presents unique problems. An atlas is like a book. Each map of it can be compared to a chapter or part of a chapter. The success of an atlas, like that of a book, depends, to a great extent, on its organization.

Some of the atlases give specialised type of information ; but a great majority of them are of general nature. The number of specialized atlases is on the increase. An example of such an atlas is the Atlas of Disease Mortality in U.K. The general purpose atlases are only too common to need explanation.

The specialized atlases generally contain thematic maps of both qualitative and quantitative nature. But the general purpose maps contain locational and other information required by the general map user and some simple thematic maps. Such maps give a variety of information such as location of towns and villages, transportation and communication lines, political and administrative boundaries and physical geographic information such as types of landforms—mountains, plateaux and plains—rivers, vegetation, trade routes, etc. etc. All this information has sometimes to be shown on the same map and sometimes on separate maps.

Depending upon the nature and amount of the data to be represented atlas maps can be drawn on a variety of scales. If the objective is to give very detailed information, it is desirable to divide the area to be represented—world, a country, or a part of a country, — into convenient number of sheets. And each sheet can be represented on a page of the Atlas. But in case the data are not so detailed, and the atlas is to give only a generalized information, the whole area can be represented in a single sheet, and each sheet in turn may represent part of the total information to be represented. Thus some maps may show physical data while others the cultural data.

The atlas maps which try to give several pieces of information on a single map present complex problems. The process of this type of mapping is considered to be an aspect of complex cartography. Complex cartography presents problems which are in some respects different from those presented by thematic cartography. In general purpose complex cartography each piece of information has to be so balanced with the others that it is legible and easily distinguishable yet it appears as an integral part of the whole map. There is nothing which is suppressed in order to highlight something which is considered to constitute the theme of the map. In complex cartography more than one information has to be brought together to give a simple map.

Atlas mapping comes within the perview of small scale cartography. The data shown in atlas maps are invariably generalized. Generalization and symbolization are therefore two of the most crucial processes in atlas mapping.

The design, contents and the size of the maps varies with shape of the area and the amount of data to be represented and the market it is to cater. The design of the atlas for the children as well as the maps included in it will be different from those meant for adults. Atlas for the children is marked with a simple design. More specialized an atlas, more complex is likely to be the design. Atlas mapping is another aspect of cartography which needs further research.

CHAPTER XXII

CONSTRUCTING MAPS FOR CHILDREN, NEO-LITERATES AND THE BLIND

As perceptual abilities of different persons differ, a cartographer has to apply different designs and techniques to satisfy their especial needs. Most of the map users are, however, educated adults whose perceptual abilities are considered to be 'normal'; a great majority of the maps are, therefore, made to satisfy the needs of 'normal' persons. But there are also persons in our society who are not 'normal' from the perceptual point of view. Important among them are children, neo-literates and blind persons. They form a sizeable minority in our society and hence the necessity to cater to their needs for maps.

Children find the maps made for educated adults too complex to understand. Similarly, being illiterate during the formative periods of their life, the neo-literates are aware of things of only local importance. They know their trade in minute details, although the methods used may be traditional. They are, however, better equipped to understand things beyond their experience if presented in a familiar form.

Finally we have the blind persons who lack the faculty for visual perception. They can feel an image, if drawn in relief, with the help of fingers but they cannot see it. This being the case, a cartographer not only has to design a map which can be easily understood by touch method but also to develop a different technique of reproduction.

We can think of several other groups which require special attention from cartographers, but in this chapter we will confine ourselves to only children, neo-literates, and the blinds.

MAPS FOR THE CHILDREN

Children are the future map users. If they become interested in maps in their childhood, they will continue to use maps in their adulthood also. Many of our present day educated adults do not use maps. It is not difficult to find a book written about countries and peoples without a single map. Books with crude and repulsive maps are too many to need examples. In order that we get successive generations of people interested in map as a source of information and as a visual means of communication we must expose our children to maps. In other words, we should produce maps for the children also.

Preparation of maps for the children involves the understanding of child psychology and the process of learning. It also involves the knowledge of the needs of the heterogeneous group called children. A four years old child surely needs different maps than an eight year old child. To write about the types of maps which will suit the children in different age groups is beyond the scope of this chapter. What is attempted here is the setting out of a few general principles which can be applied to develop maps for various age groups of children.

A child has only a limited experience with the help of which he interprets the world he sees around him. The day he is born, he starts sensing the world through various organs. Gradually he develops motives towards the satisfaction of which he comes in contact with the things and events. The motivated organism senses its world, interprets it, responds to it, and then responds to the consequences of its own responses. Once the organism has passed through this cycle, it is never again the same. Its first behaviour has consequences in the form of resultant comfort, relief or satisfaction. These consequences of its own behaviour, registered and stored, become a part of the organism. It has gained new experience. It is never the same again. It continues to register the consequences of its own behaviour and thereby embarks on the spiralling and dynamic process of living, a process in which growth and change, over a period of time and with experience, play a central role.

The map is a means to provide a child with the familiar as well as unfamiliar experiences about the world in which he lives and grows. It is also the means to change his attitudes about the world around and to perceive it in its true perspective i.e. interrelatedness. It can also be a means to change motivations and thinking. As a matter of principle, a child should learn to read and draw maps as early as possible. It cannot, however, be done before he reaches the age of six or seven. It must, however, be kept in mind that a child of six or seven cannot realize the extent to which the representations on

maps are only symbolic. And, therefore, he cannot be expected to form an adequate conception of the relations which they bear to reality. If he is given a complex and 'meaningless' map, his mind will tend to fix and relate impressions which are grotesque and untrue and which by their very clearness in his mind, as well as because they are being fixed so early in life, will be difficult, if not impossible to correct in later stages. It is unfortunate indeed that, in the absence of suitable maps for the children, we make them use the maps made for adults and thus force them to develop wrong ideas about maps and so also about geography.

Up to seven years of age a child learns through his personal observations alone. He is curious to know everything he sees. He does not, however, concentrate on any one object; he likes to change his occupation frequently. By the time he is nine years old the power of observation and muscular skills increase, and he develops a better mechanical memory and an equally good receptive mind. He uses his newly acquired skills and intelligence to sort and analyse the impressions he gathered earlier indiscriminately. He is able to understand some simple explanations and relationships. Maps for a child of seven or below should represent only the home and school surroundings to which he is familiar. These maps should be attractive, colourful and simple in design.

Mapping the class room is a time-honoured method that still has much to recommend it. Class room is chosen because the whole area to be mapped is in sight, and is equally familiar to all. Problems in making such a plan are those connected with the representation of space relationship of one object to another. Relative size (Horizontality), distance and direction of all important pieces of furniture have to be considered. Regional distinction showing a distributional pattern can also be made when part of the room is filled with desks is differentiated from that which is clear. The class room plan is indeed a map. It must be oriented with north at the top.

A nine or ten year old child should be initiated to the plan of his neighbourhood. His first step in the use of a neighbourhood map is to go out, like a geographer, with the map in his hand, and relate it to the area it represents. This procedure will help him discover how truly and by what means the maps show facts that he has come to know and perhaps reveal some of those he did not know. The procedure can be reversed also. The children may be taken out with a sheet of paper and stopped at important points to draw the plan of the routes and features visible to them.

Maps of local areas and neighbourhood on 1:2,500 to 1:10,000 provide a child with a fascinating occupation. He enjoys walking over the area and

trying to identify what he sees with symbols on the map. Even 8 year old gets exited if something on the landscape, a new house or a pond, does not appear on the map. Gradually such a map can be reconstructed to depict simple differences in the distribution of things such as agricultural area, school area, and so on. Emphasis should be laid on the representation of the phenomena which are familiar to the boys and girls of this age with familiar symbols. For example, the distribution of animals can be shown by locating recognizable figures of animals on the map (Figure 217). Children should also be introduced to the maps of the world.

By the time a child is 11 or 12 years old his critical sense is further developed to enable him to sense the conflicts between the realities of the world and the ' theories ', ' concepts ' and experiences he acquired earlier. The period between 12 and 15 years is the period of adolescence when a child tries to discard what is appropriate to childhood but is unable to be a part of the world of adults which is too complex to understand. This is the age of correlation and classification. Maps for the children of this age-group should show the interrelationships underlying the various geographic phenomena — natural as well as cultural. This can be done by relating the home area to the district, state and the country.

After the age of 15, children use reason more and more in order to understand the world and their own place in it. This is the period of generalization. Knowledge is classified and discarded or synthesized into workable instruments according to its usefulness in every day life. It is at this stage that complex maps made for educated adults should be given to them.

The use of the globes and world maps should go together. Only broad details should be shown on the world maps to be used by the children of thirteen years or less. For children above thirteen years, the symbols used in the maps need not have direct relationship with the shape of the phenomena represented. Various abstract symbols like dot, circles and lines can be used to depict the data.

Details on the maps for the children should be generalized and the portrayal should not be devoid of æsthetic beauty, colour and attraction. The first map used by a child should be one which has been drawn by himself and the teacher should continue to provide opportunities for the child to develop his skills in the making and reading of maps.

It is clear that we are not yet definite about the contents and design of maps for the children. We adults appear to under-estimate the capabilities of a child to comprehend and understand the world. Considerable research is needed before we can arrive at any satisfactory conclusion.

A Pictoral Map of South America

Figure 217 : A map for the children.

MAPS FOR THE NEO-LITERATES

Neo-literates are those persons who acquire literacy in their adulthood. For all practical purposes they are ' normal ' adults except that they do not have as much experience with the world outside as others have. An illiterate man might have heard of the world being round, but he has no faith in the idea for he fails to understand the logic behind it. He neither has the opportunity to go round the world, nor he is able to read the accounts of such voyages. Similarly, he might have heard of wheat being produced in certain parts of India but he does not know the location of these areas. Maps for the

neo-literates, then, should concentrate more on locational and distributional details.

Unlike a child, a neo-literate is more interested in locating the known facts about his neighbourhood, the country and the world. He is interested in knowing about the location of things he deals with in his day-to-day life. He is concerned about the administrative divisions of the country and state ; he is interested in knowing the international boundaries ; and he is curious to know about the distribution of human beings, animals, crops, towns, sea and land routes, etc.

As a neo-literate is new to maps, he is not able to interlink various details given in it if they are given in an unfamiliar way. For example, the density of population shown by patterns is less comprehensible than one shown by pictograms or bar diagrams. Similarly, the topography shown by contours is confusing but one shown by layer tinting is relatively more easily perceptible. The map in which a neo-literate is most interested is that which deals with his occupation or hoby. The representation of details in such maps should be of moderate complexity. Before he can make the best use of a map he must be given proper concept of map distance. Illiterate persons tend to equate actual distance with the distance given on maps. So if two known points 100 miles apart are separated by 2 inches on a small scale map and by 4 inches on a large scale map, he will tend to value the latter to be 200 miles because he does not know that maps are drawn on different scales. Letterings on maps for neo-literates should be big and unstylish. Pictures also play an important role in getting ideas across the neo-literates when given along with maps.

MAPS FOR THE BLIND

For the purpose of this chapter we will not make any distinction between a blind and a partially blind person. This is a group of people which lacks one of the most important senses of perception. Our eyes help us recognize the shape, size and colour of various objects. They help us know the position of one object in relation to the other. They also help us visualize the facts of the earth through the medium of maps.

When this important sense that we call 'sight' is not functioning properly, we lack the faculty to know the relative shape, size, colour and position of different things visually. What we, then, need is some other mechanism to perform this vital function. In other words we need to train some other senses to do the job that our eyes do, at least partially.

The part of our body that does this job best is the hand. Our hands with five fingers in each, can feel the shape and size of various objects, and

they, with the help of feet, can feel their relative position also if the objects are located within a walking distance. This naturally limits the extent and number of things a blind can know to expand his knowledge. We have to devise a method by which he will also be able to comprehend the shape, size and relative position of objects which cannot be reached by hand or feet. In other words, we have to prepare maps for the blind. Such maps must show the symbols in raised relief so that the blind can feel them with his fingers.

As our maps also show symbols by letters we should know something about the letters devised for the blind. The system of these letters is called the Braille system.

Braille was developed by Barbier, an officer in Napoleon's army who called his system 'Night Writing'. He was seeking a means of sending messages which could be read by touch at night without light by the men in forward positions. Braille has since been modified and greatly improved. It is based on the positioning of dots within a cell in raised relief. There are six dots in all for each Braille cell. When reproduced in various combinations they form all the letters of the alphabet, Indian numerals, and 63 different symbols including some dipthongs and other combinations of letters, punctuation marks, capitals and commonly used abbreviations.

Maps for the blind are almost as old as the Braille but the amount of effort expanded to improve and standardize the Braille has been far greater than that devoted to graphics. The fact, however, that cartographers have not devoted the same amount of time for the development and improvement of maps for the blind does not mean that such maps were not needed. The demand has been and still is very great. The latest estimate is that there are as many as 6 million legally blind persons in India alone. Of these only a few attend schools for the blind. The highly developed and standardized Braille fills the requirements for embossed verbal communication but the means available for embossed graphic communication are still relatively crude.

The construction of maps for the blind involves two basic problems: (1) the selection of symbols which the blind can easily read and associate with reality, and (2) the development of a cheap and efficient reproduction process. To devise suitable symbols for the blind is full of difficulties. In the case of the maps for the sighted people, we develop symbols which can be easily distinguished. We use standard psychological tests to judge the suitability of these symbols. But these tests, in the case of symbols selected for maps for the blind, present unique problems. More often than not, the persons tested have never seen a map before and if the person administering the test has no training or experience in graphics, the test results are likely to be highly suspect.

Symbolization is a very complex process. The drawings and their designs must be kept simple and the symbols should be distinct from each other so that, while being read by touch, they do not get mixed up, Pictorial symbols which are so useful for the sighted people are of no use for the blind because they convey meaning only if one has seen what has been depicted. The tactual symbols are easily confused by the blind. The symbol X, for example,

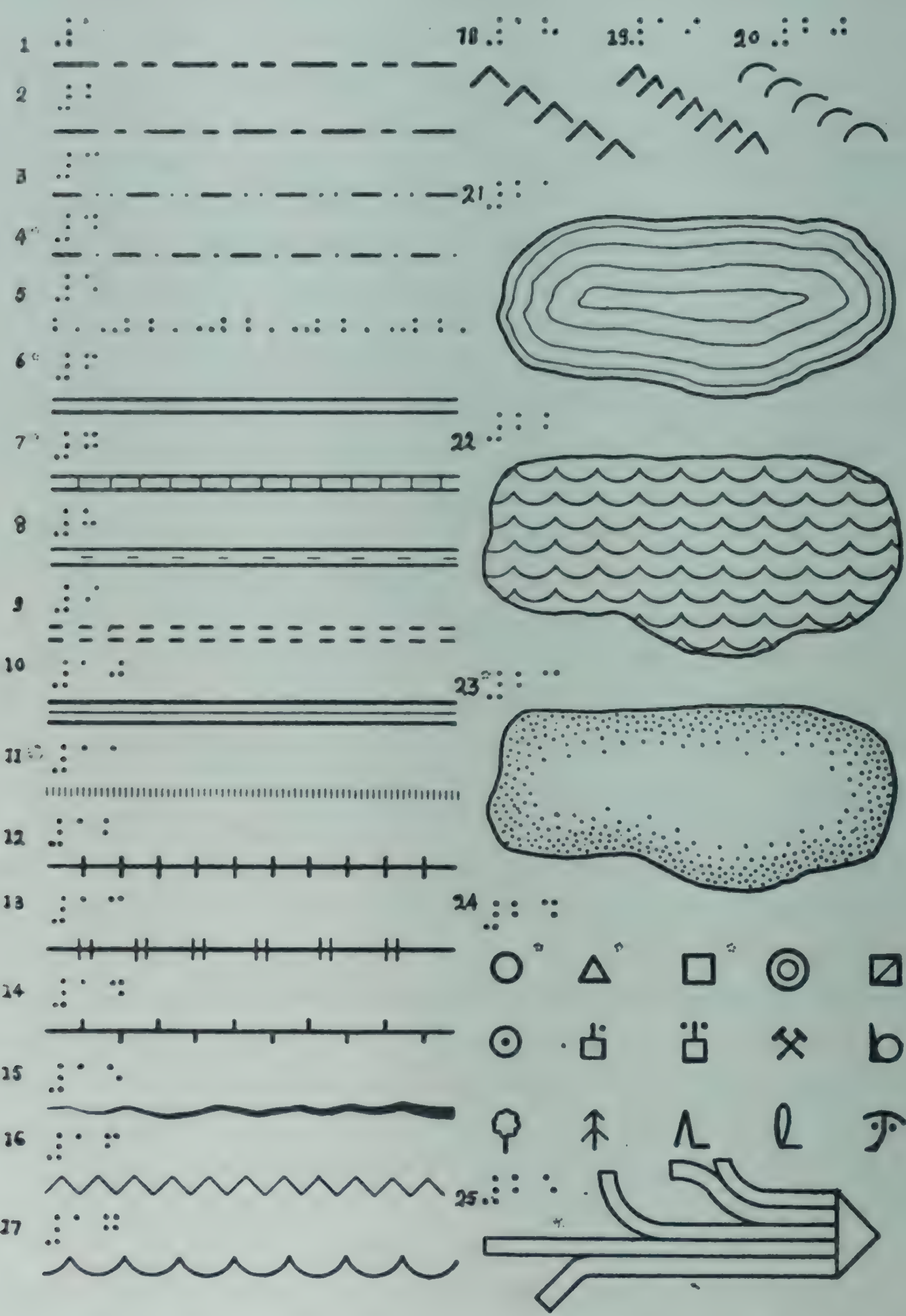


Figure 218 : Symbols for the maps for the blind (Wiedel).

is confused as a square though visually the two are quite distinct. Every symbol used must be explained and if the symbol is rotated this must also be carefully spelled out. Tests conducted at the Virginia State School for the Deaf and Blind show that the symbols indicated by asterisk in Figure 218 are tactually the most distinct ones. In particular, symbols number 11 and 23 proved to be clear, distinct and readily understandable.

The problems involved in symbolization are great indeed, but the problem of reproducing multiple copies of raised relief maps is still greater. Several experiments point to the use of a Thermocraft process which can give a raised relief of .007 inch. With research and experimentation, it can be further raised which would facilitate quick reading. The maps must be printed on glossy paper because rough paper interferes with the reading of fine symbols. The more practical method at present seems to be the Thermoform process which is slower than the above mentioned Thermocraft process but is more uniform in quality and more readily available. The Thermoform copy is also a plastic material, hence more durable.

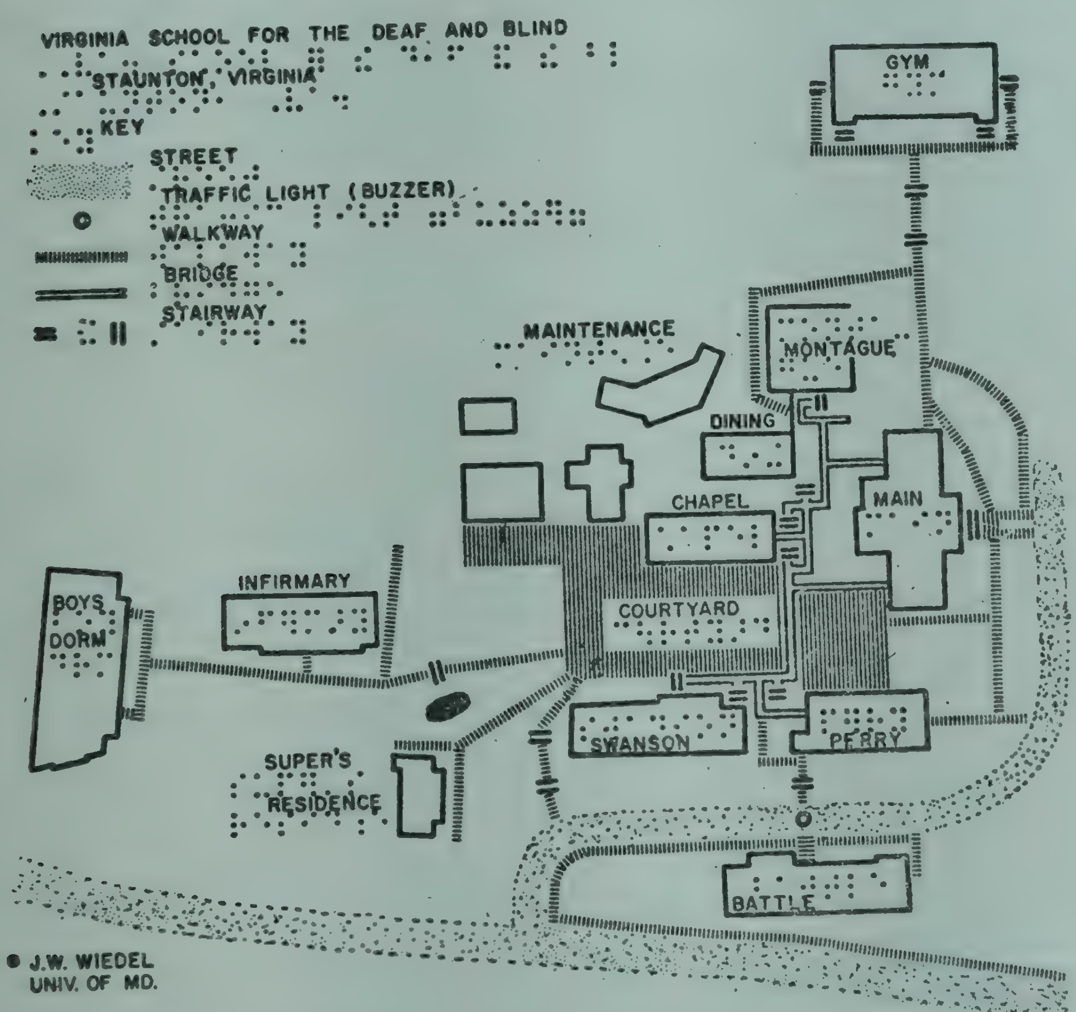


Figure 219: A map for the blind (Wiedel)

Perhaps the foremost difficulty in designing maps for the blind lies in lettering. The size of the Braille letters cannot be reduced since it is set as a standard by the International Braille Authority. The existing size of Braille letters takes too much space, making lettering on maps very difficult. One must, therefore, design various components of the map around the lettering rather than the usual method of selecting lettering to fit a given map design. The space between the Braille cells and the line-work is critical and though it does not bother some tactual readers to turn the page if the lettering is placed vertically or diagonally, for others it causes confusion. The second grade Braille is more convenient in the design of graphics since it uses a number of contractions and is known to most Braille readers. Figure 219 gives a map for the blind in which Braille letters are reduced by 50 percent.

It should also be kept in mind that nothing more than what is absolutely necessary should be included in a map for the blind. There is no need of borders and neatlines; the title should be at the top and be followed by necessary explanations and keys. The symbols should be kept to a minimum, clearly explained in the key and constructed with as much contrast as possible. Second grade Braille should be used horizontally as far as possible. If the maps are to be used by partially sighted persons also, large type can be used in conjunction with the Braille.

Lastly it must be mentioned that considerable research is needed to develop suitable designs for maps for the blind. At present there are less than half-a-dozen cartographers engaged in this type work. Perhaps no other field of cartography needs creative and welfare minded cartographers more than this.

CHAPTER XXIII

MAP REPRODUCTION

Most maps are made to be reproduced for multiple copies. Prior to the invention of printing machine, copies were prepared by exactly the same drafting method that is used in making original drawings. Copies were reproduced by copyists who laboriously and slowly duplicated the original text. All maps were made manually.

The basis of modern printing was laid in China in ancient times. During the medieaval period (15th century), the printer began with a smooth piece of wood and carved the surface until the letters and figures to be printed stood out in relief. These handmade printing blocks could be used to produce a number of copies but they could not be used again for any other publication. They became useless after use in the same way as the blocks of today.

It was around 1450 A.D. that either Johanan Gutenburg (1397–1468) or Laurens Janszoon Cozter (1370– ?) invented movable types which could be used again and again. There were several important consequences of this development, chief among which was the explosive cultural effects of the wide dissemination of textual and graphic material. Of quite another order of relative importance was the rather fundamental effects printing had upon the characteristics of lettering and map delineation.

From the invention of modern printing to perhaps the middle of the last century, the restriction on artists continued to be many, although less stringent than before. No matter which style and form of lettering was deemed desirable and what lines, symbols or colours might best convey the concept of a map, only those available to the printer and engraver could be used. Because of the overwhelming role of the technicians in the printing process their impact on the design of maps was widely felt. The cartographic products of this period were artistic but portrayed repeatedly the same design and layout.

The technological developments which took place during the late nineteenth and during this century totally eliminated earlier limitations. To day there is theoretically no reproduction constraint in the demonstration of cartographic genius. Almost any design, detail and colour can be reproduced. Among the several reproduction possibilities, there are a few which are very inexpensive but do not suit the requirements of artistic details. There are others which are expensive but give copies which not only match the original but also improve it. Some of them give quick results and are within the reach of individual cartographers. Some of them can produce only line work; some others can produce line works as well as continuous tones. Which of these processes a cartographer should use will depend upon his resources, drawing, and demand on time. In this chapter we plan to provide a brief summary of the processes with which a cartographer is likely to be concerned in his capacity of print buyer.

PLANNING FOR REPRODUCTION

Whenever a new map is being contemplated a cartographer has to give careful thought to the reproduction possibilities. He must explore all the reproduction possibilities and choose the one which is most appropriate in terms of cost, number of copies required, future use of the map, and other considerations.

Designing a map for reproduction involves a number of important considerations and techniques. One of the more important considerations is the relation between the size of the fair drawing prepared for reproduction and the printed or reproduced size in terms of the degree of detail, width of lines, and the size of lettering. As most original drawings are reduced in scale in the process of printing, maps which look well designed when in original drawing may turn out to be poorly designed when in printed form. All originals are, therefore, designed with an eye on the final product.

REPRODUCTION PROCESSES

For the purpose of map reproduction, we can divide reproduction process into two:

1. Duplicating processes ; and
2. Printing Processes.

The more widely used duplicating processes are :

1. Stencil duplication or mimeographing,
2. Direct contact positive,
3. Direct contact negative,

4. Photostat,
5. Silk screen printing, and
6. Photographic.

Among the printing processes the following are the important ones :

a) Letterpress
b) Photogravure, and
c) Lithographic.

It must be pointed out here that the above classification is in no way a satisfactory one. Many of the processes require more than one technique. The intermediate techniques in one become final in another. For example, photography is a step in printing process but it can also be considered as separate reproduction process.

DUPLICATING PROCESSES

Stencil reproduction :

Stencils cut on typewriters, so commonly used in duplicating documents, can at times be effectively used for cartographic works designed to give simple statistical facts in terms of line graphs and generalized outline maps. In India the Gestetner company sells special types of stencil sheets which are designed for such maps and graphs. The stencil maps of this type reproduce at the same scale and can easily give 500 clean copies. Such maps are devoid of refinement of drawing but are useful in draft reports which may have other matters also stencilled. A sheet of fine and porous tissue is thinly coated with wax. When this tissue is placed in the typewriter and given an impression from a type character, (without a ribbon interposed) the wax coating is cut through in the shape of the character. The tissue base remains intact, its fibres forming a web over the spaces cut in the wax. Thus the impression becomes a stencil of the character. On the duplicating machine the stencil is laid over a cylinder of metal guaze. Ink is squeezed through the guaze and then through the stencil to form an impression on a sheet of paper in contact with outer surface of the stencil.

Direct contact positive :

Direct contact positives are made by exposing a drawing done on a transparent or translucent paper placed in contact with a printing paper sensitized with light diazo compounds. The exposed paper is then developed with ammonia fumes. The resulting print is positive reading. The print one gets is of the same size as the original drawing.

While preparing an original for diazo printing a few points must be kept in view. Firstly the paper must be at least a translucent one. All drawings have to be done on tracing paper or cloth or plastic sheet. (2) All corrections on the original have to be done by careful erasing. One should not resort to opaquing of the unwanted lines by white ink, for, the white opaque would appear as black spot in the print. Creases on the tracing paper or cloth and heavy erasures which affect the translucence also appear black on the print.

Direct contact diazo prints are ordinarily obtained by feeding the original drawing together with the diazo sensitized paper in a machine in which, the exposure and dry developing take place simultaneously. But some of the machines have a seperate chamber for dry developing. After the paper is exposed, it has to be manually put in the chamber for developing. (Fig. 220).

While making originals a cartographer may use Zip-A-Tones for areal patterns or stick-ups for lettering and symbols. As the original has to move along a glass cylinder in the machine which is lighted by strong tube lights, it gets heated in the processes of exposing the diazo paper. As ordinary zip-a-tones and stick-ups are wax backed, they slide off their positions when the wax melts. So if these materials must be used, they should be of improved type which are not subject to this type of deficiency. The diazo prints are not very stable and fade away with time.

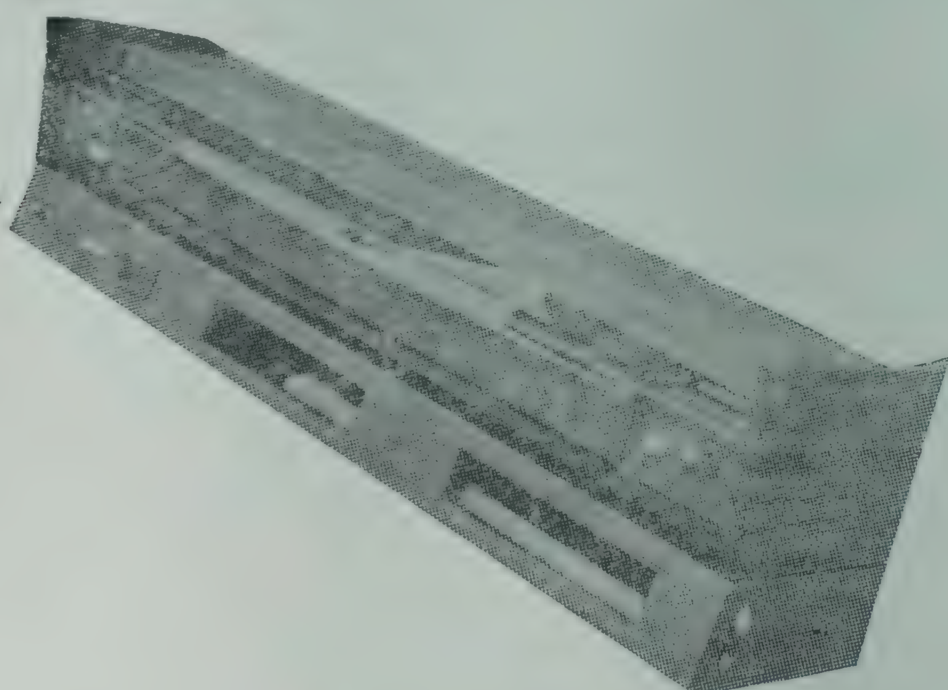


Figure 220: Duplomat: An amonia printing machine

Direct contact Negative:

This process is commonly known as blue-print process. In this process the copy is laid next to an iron-sensitized paper and is then exposed to special

lights. The exposed print is wet-developed and is, consequently, subject to some distortions. The prints appear as right-reading negatives, that is, what is black in the original appears white in the print. The negative is then used to get a positive. This process helps in obtaining a few relatively inexpensive copies. Several smaller engineering units use this process to get copies of building plans etc.

Photostat or Photocopy :

This process is something in between photography and diazo printing. It provides prints in reverse on sensitized paper, without the necessity of any intermediate film step. It involves the exposure of the original drawing through a lens directly to a senstized paper which is then wet developed. The developing process and the subsequent drawings frequently cause unequal shrinkage, so that some distortions in dimensions and directions often creep in a photostat copy.

First of all a reversed image (negative) of the original drawing is obtained. The negative is, then used to get a positive. If a drawing having black lines on white background is photo-copied, the paper negative will have white lines on a black background. To get positive copies (same as the original), it is necessary to repeat the process using the negative as the original.

The advantages of this process, as against the direct contact process, lies mainly in the fact that one can enlarge or reduce the original drawing to a desired scale. The only limitation is the size of the sensitized paper used in this process (18×24 inches). Many time saving and useful results can be obtained by using the photocopy process in cartography. We have already mentioned its use in reducing and enlarging a map. It can also be used to get stick-up lettering or white letters on black blackground. It is much easier than attempting to write with white ink on black background.

There is yet another way this process differs from the amonia printing process. In this process the original does not have to be drawn on a transparent or translucent paper. Drawing mistakes can be corrected by opaquing the wrong parts. The primary use of photocopy is to obtain a few relatively inexpensive duplicates of a black and white map.

Silk screen printing :

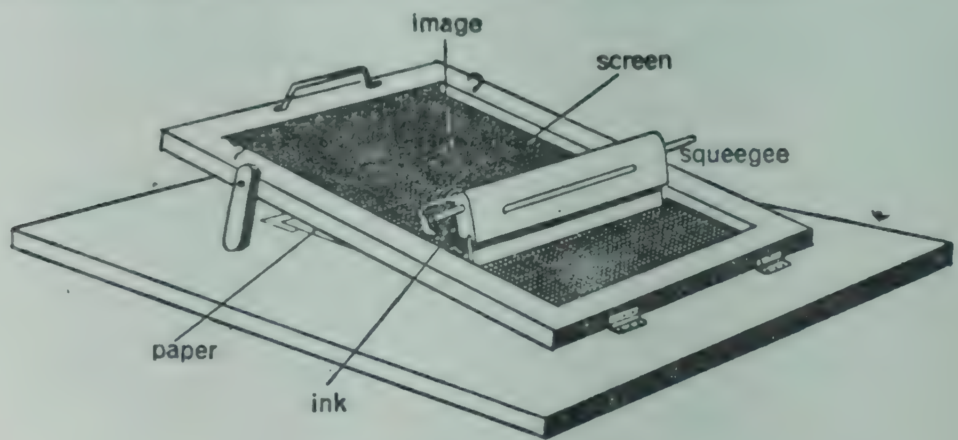
This process, now commonly known as " Screen process printing ", has varied uses. The origin of screen printing is uncertain, but it appears to be based on the early Chinese method of stencilling. It is not known as to who

invented modern screen process printing but it is known that in 1907 a man named Simon was granted a patent for a printing process which involved the use of a screen. Screen process printing is now used in nearly all the countries of the world.

Its wide use results from its evident advantage as an efficient and economical method of graphic reproduction. It is essentially a handicraft process, using inexpensive machinery. Almost everything needed in this process can be made at home at little or no expense. What is called the basic equipment for this process is a printing frame and a piece of silk cloth. The printing frames may vary in size depending upon the size of the diagram or map to be printed. A picture of the frame is given in Figure 221.

It sits on a baseboard which can be made firm. An old drawing board or a piece of plywood slightly larger than the frame is enough. A screen of silk or linen is fixed into its groves.

After mounting on the frame the screen should be washed and soaked in warm water to remove all sizing that it may contain. Upon drying, the fabirc will slightly shrink and will have to be stretched on the frame.



Screen-process printing

Figure 221 : Screen process printing frame.

The stencils can be made from a variety of materials including good drawing paper, but the best results are obtained by making them out of films. The design and value of the image will depend upon the nature of the drawing and method used in stencil cutting. Making the stencil constitutes the core of silk screen printing. Upon it depends the success or failure of the work.

The process works something like this. Lay your cut out film stencil on the positioned paper on which the image is to be printed, film side up, in exactly the position you want it to print. Lower the screen on it, and check that the silk is in perfect contact with the stencil all over. Have two pads of soft cotton rags ready. The best kinds are those made from men's older undershirts.

Moisten one of the rags with adhering solution. Rub the moist rag over the silk with even strokes of about 5″ to 6″. Soon after it, rub the same spot briskly with dry cloth in order to help the thinner to evaporate quickly. As a result of the rubbing of lacquer thinner, film coating is softened to create glue which sticks to the screen. Allow the silk to dry for about 10 to 15 minutes. Then raise the screen, and with your finger nail loosen the glassine backing from the adhered stencil. Start in one corner and slowly peel the backing off the whole sheet. In case the stencil does not fill the entire area of the screen, the unwanted parts should be painted with lacquers so that only stencilled portions of the screen will be left without the adhesive lacquer. The film stencil is now ready for printing.

Now lay a sheet of paper on the baseboard of the frame and well up against the stop guides. Lower the screen and see that the paper and the silk are in even contact with each other. If the stencil does not rest firmly on the paper, you may have to slip a cardboard under the latter. Stir your paint to mix up the oil vehicle and pigments. Pour a liberal quantity of the mixture on the blanked out upper part of the screen, arranging it over the whole width of the stencil. Take your squeezee blade; incline it to a 60 degree angle and holding it with both hands, pull it in one continuous sweep over the whole stencil, exerting moderate downward pressure. Now you get a printed copy. Repeat this procedure for each copy. After removing the copy from the frame it should be left on a table to dry. After the printing is completed, the screen should be cleaned and used again. The principle of screen process printing is illustrated in figure 222.

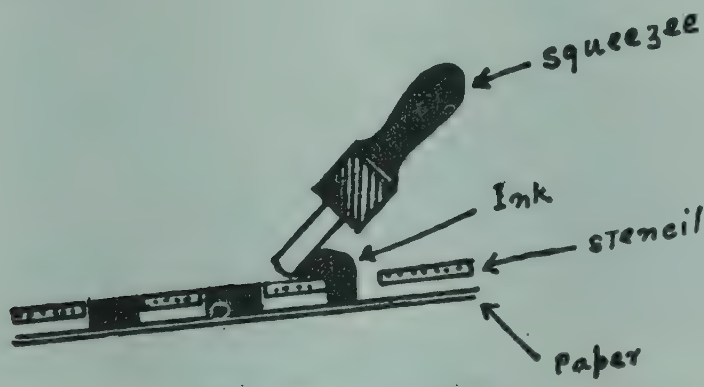


Figure 222: Principles of screen process printing

Photographic process :

This process involves a camera, film negative and photographic paper. Cameras are of various types and perhaps the best investment a geographer-cartographer can make is a good camera. It is better to have three cameras: one for 35mm colour rolls, the second for black-and-white pictures and the

third for large portraits. The smaller cameras are useful in the field while process cameras are useful in the laboratory. A process camera is used for photographing large maps, either for compilation or reproduction. For a cartographic laboratory, a process camera (Figure 223) is a must

The simplest way to photograph a map is to fasten it to a gray cardboard and to place it outdoors. The lightmeter will give the exact time for exposure for each shot. Focussing is important and the camera must point perpendicularly to the centre of the map. No shadow should fall on the map. The exposed photographic film is developed, fixed, washed, dried and trimmed. The minimum equipment of a dark room consists of a table large enough for four trays which can accommodate films, running water and sink, a drying rack or string, a cutter, frames for positive copies and shelf for chemicals, films, papers etc.

To develop the exposed films, we need a mixture of chemicals called developer. When unmixed with water and stored separately, it keeps for a long time, but once mixed with water, as required in developing, it lasts only a day or so. Therefore, we mix the two only in amount needed at a given time.

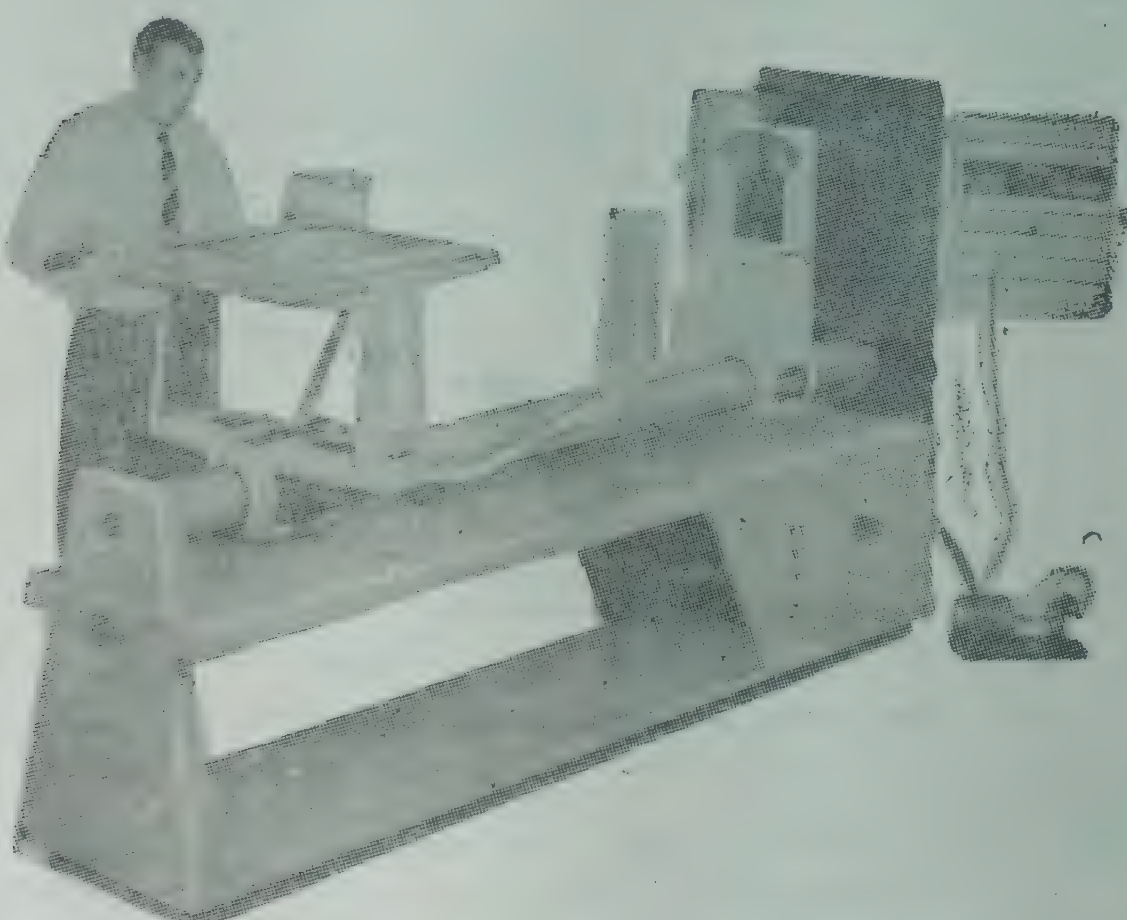


Figure 223 : A dark-room process camera.

The exposed portion of the film should not be touched with fingers before dipping into the developer. When developed, the film is transferred to the next tray containing the weak solution of acetic acid which halts the development process in about 10 seconds. It is then placed for 2 to 5 minutes in the third tray containing hypo after which the light can be switched on. Here the image is retained but the rest of the emulsion is washed away. The fourth and the final bath is given in a tray or sink in which film is allowed to take off the hyposalts within about 10 minutes. (Figure 224)

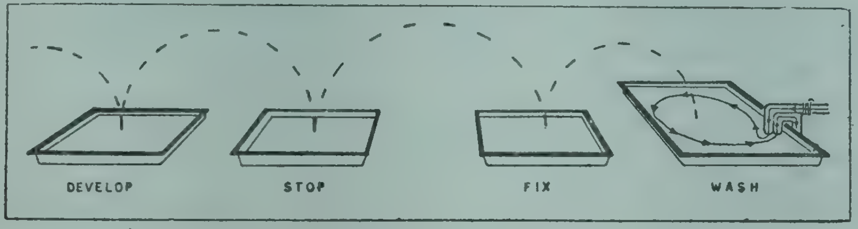


Figure 224: Film developing process.

A camera gives us a film negative. The size of the negative depends upon the type of camera. 35 mm camera gives only slides which can be used to get larger prints. Large process cameras give large size negatives. If the size of the desired photograph is the same as that of the negative, the negative can be placed over the photographic paper to get the latter exposed by turning the light on. This works like any direct contact printing process. But if a smaller negative is used, it will have to be enlarged by an enlarger to get larger prints.

PRINTING PROCESSES

In the previous section we discussed those duplicating processes which can give us only a limited number of copies. In this section we propose to deal with those processes which can give practically any number of copies. These are:

1. Letterpress or relief process,
2. Photogravure, or intaglio process, and
3. Lithography or planographic process.

Letterpress:

In a literal sense, letterpress means the composing of letters with raised relief and pressing the composed letters on paper to get an image (figure 225). A cartographer is not concerned with the letters, he is interested in the process used in getting the image. He wants to use this process for printing maps and other graphics. The method by which this is done is called process engraving.

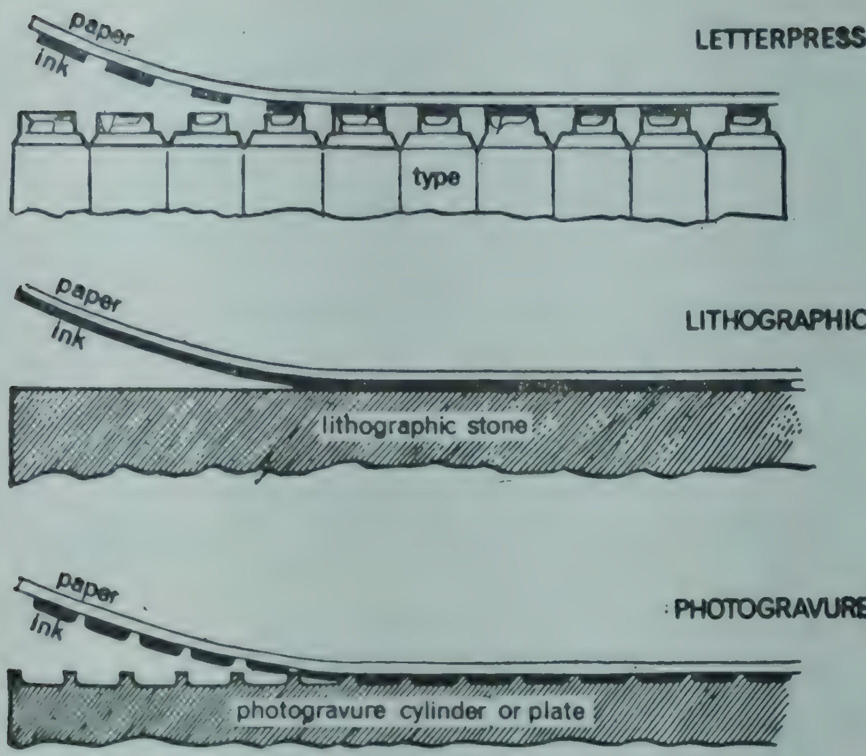
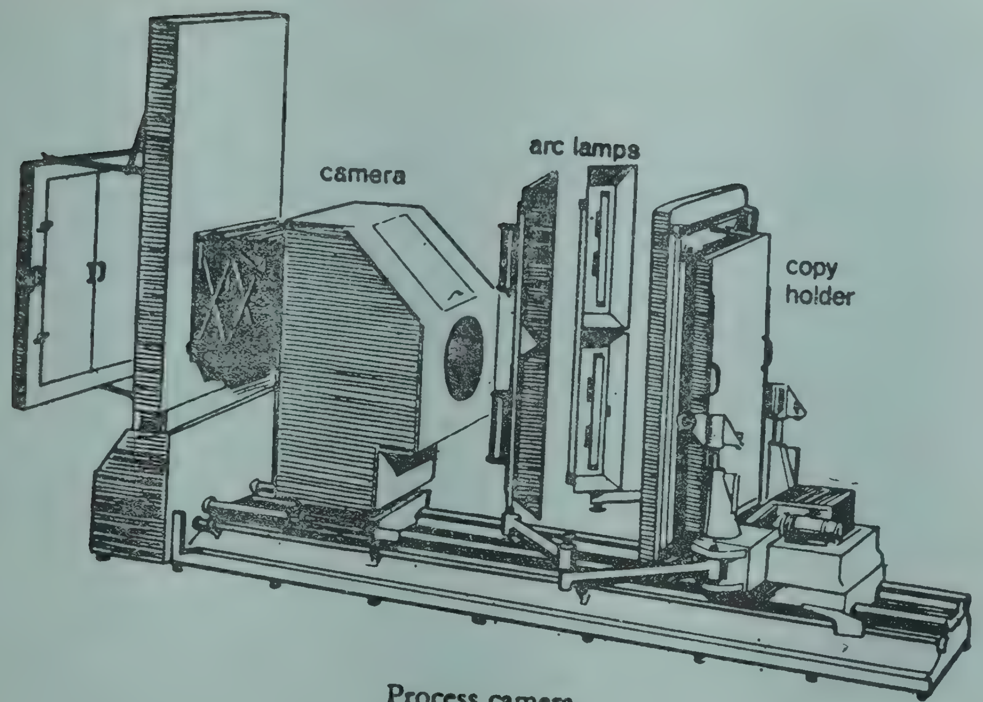


Figure 225 : The three methods of printing

A black and white drawing that does not have degrees or tones of shading can be reproduced with the help of a line block ; the reproduction can be on a size different from the original, if so desired.

The original drawing is attached to a very brightly lit board called copy board in front of a process camera. Contained within the camera are mirrors which reverse the picture from left to right so that when the resulting block is printed it appears the right way round. In older installations, the copy board is set at right angles to the camera which has a prism mounted in front of the lens. The prism has the same function as the more modern mirror system (figure 226).

The negative produced by the camera is printed on a zinc plate sensitized with a solution of dichromated albumin which, when exposed to light, becomes insoluble in water. After exposure, the plate is coated with a special ink and placed in water. This dissolves any unexposed albumin and leaves a reverse copy of the original drawing in hardened ink covered albumin. When dry, the image is covered with a bituminous powder which, when heated, mixes with the ink and forms an acid resistant finish. The edges and the back of the plate are varnished. It is immersed in nitric acid which erodes or etches the plate where it is not protected by the bitumin or varnish. The resultant plate is then mounted on a piece of wood about 1 ″ thick. The mounted plate is known as a block.



Process camera

Figure 226 : A process camera used in block making

A block can give only a single colour picture. More than one colours can also be reproduced by this method, but a seperate block will have to be made for each colour. The originals for the multicolour letterpress printing can be drawn by any of the two methods (1) one original for each colour, and (2) only one original but the drawings done in the colour they should finally appear. If the first method is used, the process will be the same, as described above except that each original must have registration marks on its four corners, so that when all registration marks are made to coincide, the desired images also come at their appropriate position. If the second method is used a little different way of photography is needed. If the original drawing is in yellow and blue, the camera would normally record both colours simultaneously though in different shades. To prevent this, a filter is used on the camera lens to eliminate one colour whilst the other is being photographed. In such a case two negatives are made and the resulting two line blocks print their respective contributions of colours to complete the map.

So far we have dealt with the printing of the line work. But if a drawing with continuous colour or one with the gray of various shades is to be reproduced, one has to use the half-tone process of reproduction. The varying tones, as visible to our eyes, are illusions and are obtained by dividing the printing plate into minute segments with the help of dots.

This is done with the help of a screen which produces a negative in which dark areas are represented by patterns of very small round dots and the

bright areas by a pattern of coalesing dots. Various tones are obtained by different size dots between these two extremes (Figure 227).

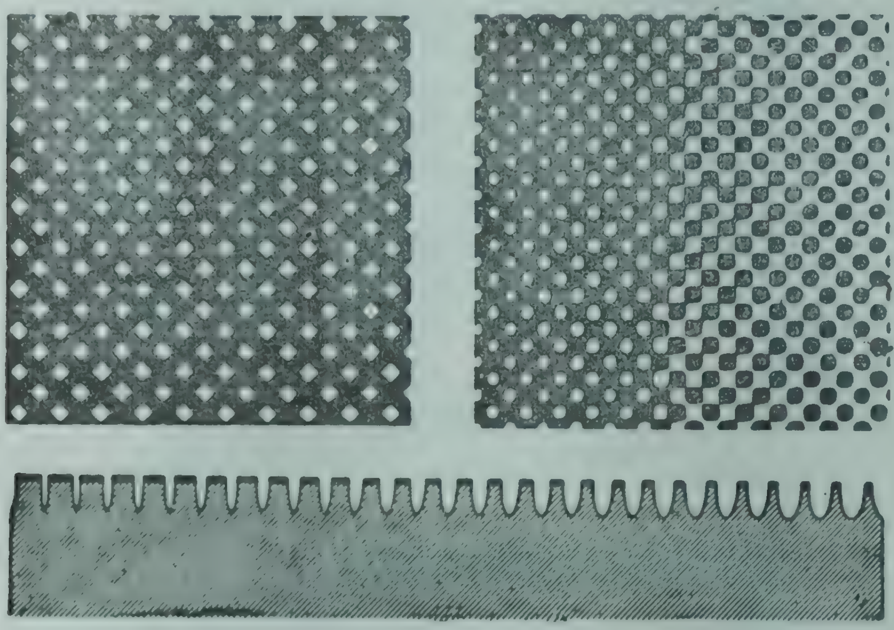


Figure 227: Appearance of half-tone under magnification.

A half-tone screen consists of an optical glass with parallel lines cut-out into the glass with a diamond shaped tool and the lines filled with an opaque material. Two pieces are cemented together with the lines at right angles to form the screen. Various screen rulings varying from 50 to a maximum of 200 lines to an inch are used for this purpose. Generally speaking, poorer the paper, coarser the screen demanded; news papers use a 60–65 screen, art or shiny surfaced papers require about 120 to 150 screen.

The process works something like this. The drawing to be reproduced is placed on the copy board. The screen is placed inside the camera just in front of the unexposed film and the image formed by the lens is broken up into thousands of points of light which are strongest where the photograph is the lightest. The resulting negative is used in the same way as a line negative, but if the plate is made of copper, it is coated with dichromated fish glue. A new method of producing a half-tone screen is to incorporate the image of a half-tone screen pattern in the emulsion of the film during its manufacture. When the film is exposed in the process camera to the photograph or drawing, the dot pattern is produced automatically as if a conventional screen had been used. This film is ordinarily made with a screen ruling of 133 lines to an inch.

After exposure, the print is developed by dissolving the soluble glue in water. The remaining glue image is converted into an acid-resisting enamel

with heat. The plates are then etched with ferric chloride which dissolves the metal between the dots, thus leaving the dots standing in relief. The plate is then mounted on a block.

Half-tone colour reproduction is the most scientific of all photo-engraving or process work. Three colour printing requires three half-tone blocks, one for each of the primary colours–yellow, red and blue. With these colours the printer can make a casual observer believe he is seeing almost every colour imaginable. To obtain the necessary negatives, the same process of putting filters in front of the camera lens is used. To get yellow block a violet filter is used, which prevents the green and red from being photographed. Similarly a green filter is used to get red and a red filter to get blue.

The blocks mentioned above bear negative images. When they are letter pressed on paper, they give a positive image. It should be noted here that in letterpress printing the block making is rarely done by the printers. The block makers are called photogravures. Before making the originals, the cartographer should first know the printing process through which the drawing is reproduced. If the process is letterpress, then he should know whether he should prepare separate drawings for each colour or not. It is, however, advisable to prepare separate drawings because drawings done with other colour inks do not appear sharp. After completing the drawings and before sending them to the press, he must write down clearly on the back or the margin the colour in which each drawing is to be printed.

Electronic engraving machine has made this process much quicker. It does away with the work of the camera, printing on the plate, and a great deal of etching. Two well known machines are the Vari-Klischograph and Fairchild. The first can enlarge or reduce and produce a printing plate up to 12 inches by 17 inches from photographs, transparencies or drawings.

The letterpress printing machines which use raised relief drawings and letters for printing are of various types. Until recently they were flat bed type but now rotary letterpress printing machines are also in the market. In both the cases, the raised relief is given a coat of inks with the help of a roller and then sheets of printing paper are brought in contact with it successively. The paper is pressed either by plater or cylinder to reproduce the image on the paper.

Engraving :

Engraving is another method of reproduction. It was also developed during 1850. This process is exactly the opposite of the letterpress in so far as the creation of the printing plate is concerned. The white parts of the original drawing are left intact and the black ones are encised. This is also called intaglio process.

All intaglio plates are printed by filling the incisions with ink (Fig. 225). The surplus ink is wiped off from the surface of the plate and the paper is pressed on it. The paper is forced into the depression taking up the ink and retaining a slightly embossed effect characteristic of engraving and etching.

The most immediate material to be considered in the making of a bitten line etching is, of course, the metal plate upon which the design has to be engraved. The traditional metal for this purpose is a good grade of pure copper. Zinc is the other suitable metal for this purpose. But zinc, being more brittle than copper and also being softer, gives less number of satisfactory copies.

The art of etching is based upon the corrosive action of the nitric acid on metal. When we immerse a polished plate in an acid solution, the etching takes place indiscriminately. We must find a way of restricting the action of the acid only to the places where it is wanted. To do this we cover the entire plate with an acid-resisting film of wax compound called 'etching ground'. Bee wax mixed with other ingredients makes an ideal ground.

The plate is then smoked a bit before any drawing is rendered on it. The drawing is done with a needle so that the drawn portions are without the 'ground'. This plate is then put in a tray of acid. Acid starts eating away the copper exposed by drawing. It may be mentioned here that the back and the sides of the plate are applied with arphattum which does not allow the acid to corrode there. The plate is removed and a varnish, which stops further etching, is applied with a brush. If the etching is not sufficient the plate is put in the acid again.

After final etching is completed the plate is cleaned and wiped. The etching ink is fed in the groves. The plate is then ready for printing. Considerable force must be exercised to press the paper fiber into the depressed lines from which they must lift the ink deposit. Evenly rolling pressure of considerable force is the secret of all intaglio printing.

Lithographic process:

This process is a planographic process i.e. the printing and non-printing surfaces are on the same plane, and is based on two well-known principles: (1) greese and water will not mix and (2) water will not wet greese. It was invented by Johanan Aloys Senefelder (1771–1834). He found that drawings done on smooth surfaces of limestone with crayon can be reproduced, after the stone surface is moistened because the crayon repels water but picks up the greesy ink whereas the moist surface of the stone repels the greese. Because of

this original use of stone in this process, it came to be known as lithography. With the advent of direct lithographic rotary printing machine, it was, however no longer possible to use stone. At present only zinc and aluminium plates are used for this purpose. These plates are light, cheep, and occupy very little space when stored.

In the early stages of the development of lithographic process, the cartographer had to draw or transfer a reverse image on the plate to get a positive image. With the introduction of camera and sensitized films the problem of drawing or transferring the image on the plate is no more there. In fact today we do not have lithography; it is photo-lithography which combines photography and lithography to produce a printing image.

To Make a printing surface for photo-lithography a zinc or aluminium plate is first thoroughly cleaned and then placed on the bed of a graining machine which consists of a shallow tray oscillated by an electric motor a few inches either way (figure 228). The plate is covered with steel, porcelain or glass marbles. Cartorundum powder and water are sprinkled when the tray starts moving. The action of the cartorundum and marbles roughens or grains the plate so that it can retain water or ink.

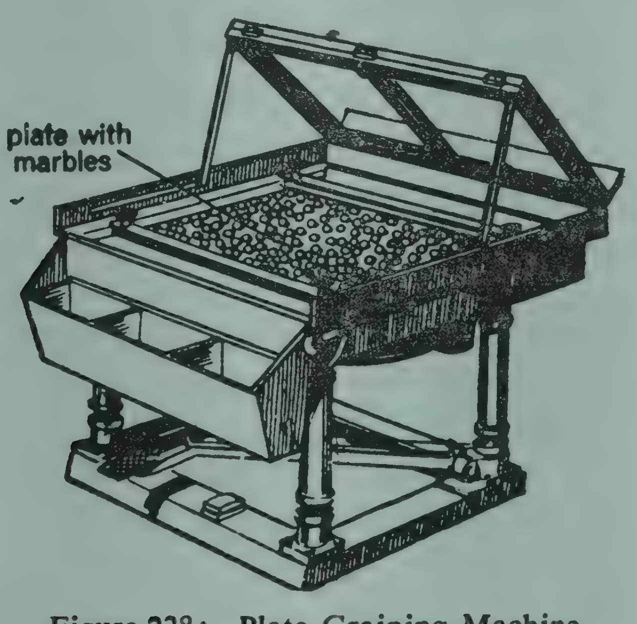


Figure 228: Plate Graining Machine

Albumin mixed with water and ammonium dichromate is poured on the plate. An even coating of the solution is ensured by putting the plate in a coating machine or 'whirler'. A whirler is a high speed revolving table with a lid and a heater to control the thickness and drying of the solution. When dry, the plate is removed. This plate is now sensitive to light. A negative of the image to be printed is placed upon it, and both are exposed in a printing–

down frame which is vaccum exhausted to ensure complete contact btween the negative and the plate.

When exposed to bright light, a reaction takes place between the ammonium dichromate and the albumin. The transparent areas harden to produce the image and the areas covered by the dark parts of the negative remain soluble. This plate is covered with a special developing ink and then washed. The washing removes the unexposed albumin and the layer of ink. The printing image is left in insoluble albumin covered with ink. The plate is now desensitized by coating it with a solution of gum arabic so that it is not affected by light any more.

Tone gradation is created in litho in a similar manner as already described under ' process engraving '. The colour printing by this process is basically similar to colour printing in the letterpress. A seperate plate is made for each colour and printed separately on another machine, or at the same time on a multi-colour printing machine.

The lithographic printing machines are of three main types : (a) direct flat bed, (b) direct rotary, and (c) offset litho. A direct flat bed lithographic printing machine is similar to a letterpress machine but it has additional rollers to dampen the ' stone '. The direct rotary machine has two cylinders which revolve continuously one against the other. One cylinder has a plate which is alternatingly damped and inked, and the second cylinder carries the sheet of paper on which printing has to be done. The most modern of the machines is the offset rotary machine. It was invented by Robert Barclay in 1875. Basically the machine consists of three continuously revolving cylinders (figure 229). The first cylinder carries the printing plate with its damping and inking mechanisms, the second carries a rubber blanket, and the third the paper. The plate cylinder with the image the right way round, prints on to the rubber blanket on which the image appears in reverse. The image appears the right way round when transferred from the rubber blanket on to the paper. This is known as offsetting. Offset rotary machines, when fitted with automatic paper-feeders, print at a very high speed. The offset lithographic colour printing machines are usually built in units. Each unit prints one colour.

RECAPITULATION

The basic steps in the printing process, from the time the printer receives the copy to the time he delivers the printed maps, are much the same whether the process is letterpress or lithographic. In general the process consists of the following operations :

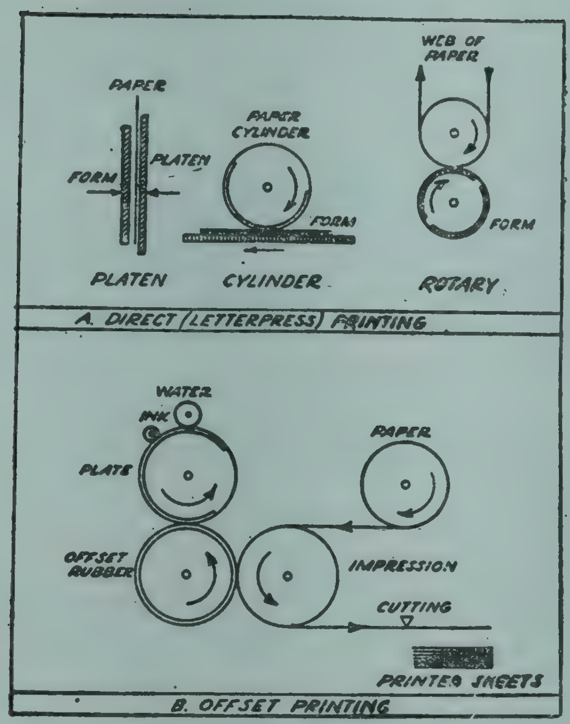


Figure 229: Lithographic printing: direct and offset

1. Photographing the original drawing,
2. Processing the negative,
3. Making the plate, and
4. Printing.

Photographing an original drawing is a very exacting process requiring the use of an expensive copy camera. It is a huge and rigidly mounted camera capable of making large or small exposures. The copy is first placed on a vaccum frame with a glass cover. The frame holds it perfectly flat. It is then exposed for several seconds under illumination by arch lights. A relatively slow film is used in order to give the photographer greater control over the quality of the negative. The quality of negative depends largely upon the quality of the drawing, presuming that the photographer is an expert in his trade. The original should have dense and uniform black ink otherwise the negative does not come out satisfactorily. Any reduction in the scale of the map is done at this stage because the negative is produced at the scale at which the printed map is planned.

The next step is the processing of the negative. It is one of the most important steps in the cartographic technique, for it is at this stage that some of the short-comings of drafting can be removed. Negatives for multi-colour can be had in two different ways. One way is to prepare separate original for each colour and the other is to draw all the drawings in one

original but give a colour separation guide to the printer. If the latter method is used, then as many master negatives are taken as the colours. With the help of the colour guides only one colour details are kept in a negative. As the drawing appears in transparent white, it can easily be duffed or opaqued.

Giving a finishing touch to the negative is called retouching. Retouching involves the duffing off the pin holes and other unwanted details. It also involves corrections and refinement of the negative. The plate making process has already been discussed in detail.

SOME LATEST TECHNIQUES

We have discussed how changes have taken place in the processes of preparing negatives and plates and final printing of maps. Almost all these processes are now highly mechanized. But changes in the techniques of doing original drawings had not gone that far. It is true that we have now better drawing equipments and tools which make the cartographer of 19th century envy us, but the fact remains that much of the drawings have to be done manually and manual skill cannot be dispensed with in cartography.

A few recent developments, however, appear to have made it possible to have a short-cut between the original drawing and the photographic negative. Although manual skill is required here too, in many cases it has become possible to dispense with the ink drawing altogether and to start with the negative itself. One such technique is called 'scribing'.

The difference between scribing and conventional drafting is this: Conventional drafting deposits on the surface of a transparent or translucent sheet of paper or film a line of graphite or ink. Scribing, on the other hand, removes the opaque coating from a plastic sheet in narrow lines allowing light to pass through and resulting in a negative image i.e. the background is opaque, and the image lines are transparent.

A scriber is the main tool for scribing (figure 230). It can be made of a phonograph needle or a tungsten carbide point which has been ground to give a specified line width. Scribe points can also be made of saphire. For line drawings the scribe point can be held in a holder; it can also be held in a pencil clutch of an ordinary compass for circle scribing. Where corrections are to be made, instead of erasing as in conventional drafting, the error is filled in with a soft crayon or with a touch up paint specially made for this purpose.

The scribe master which we get after scribing a sheet cannot be used in the same way as conventionally drafted drawings for reproduction through the

Figure 230 : Scriber

medium of either semimoist or dry type Diazo. The reason is that the scribe master is a negative image and hence a diazo print of it will give only a negative image. The scribe master is, however, well suited to all those reproduction systems which work through negatives, such as silver photographic method, blueprint, brownprint or the wash off system. The three major areas in which scribing is being used to day are mapping, aircraft and automotive manufacturing and electronics. Today's multi-coloured maps may contain four to seven different colours. For doing color separation, scribing lends itself beautifully. A positive compilation which is a pencil or ink drawing on transparent film base has all the features which will appear in the final map. This is contact printed on Diazo sensitized scribe coat material. As many such sheets are necessary as there are colours in the finished map. A different scribed sheet is required for each colour. For instance, contours are normally printed in brown so only the contours are scribed on one sheet. The culture, being usually printed in black, is scribed on a second sheet. The extreme dimensional stability of the base and the relatively great accuracy by scribing combine to make maps clear and concise.

Scribing has certain overriding advantages over conventional drafting. First the accuracy which is obtainable through this method is unsurpassable. No other method of drafting whether it be inking, penciling, or taping can compare to the controlled line-width obtainable by scribing. Pencil under magnification shows an extremely ragged line. The individual particles of graphite do not overlap, so the line is not completely opaque. This, of course, is also true of an ink-line, the density of which fluctuates due to the sharpness of the pen used and the amount of ink flow. If the pen has just been filled it, will form a wider and more opaque line than if it has been used to draw some length of line. A scribed line, will always maintain its width right down to

the final point of drawing. Corrections of errors in either pencil or ink drafting will leave smudges or show damage to the surface of the material, as well as ghosting. These often make unsatisfactory reproduction. A scribed original, on the other hand, being opaque over its entire surface except for the open lines, will not show smudging or ghosting. The filled in lines are opaque so that new lines may be scribed to correct any errors. Since the scribe film is a polyester base and the coating is completely waterproof, the resultant master is more lasting.

Secondly, one of the most important aspects of scribing is the rapidity with which it can be learned or taught. It has been found that the scribing technique requires approximately one-third less time to learn than conventional drafting. Tests have been conducted in which a group has been divided with half doing a job with conventional drafting methods while the remainder using the scribing technique. Results showed that thirty to fifty percent more work could be done in the same length of time by a scribing group than could be done by a drafting group when both had the same amount of practice. Although conventional pencil drafting is faster than scribing, ink drafting is about one-third slower. No drying time is required in scribing as is necessary in ink drafting. Additionally, there is far less tension on the part of an operator who is scribing, since he does not have the worry of ink blots and damages to the master drawing. *

* Partly reproduced from K & E brochure. "Scribing on stabilene film."

CHAPTER XXIV

CATALOGUING, STORING AND MARKETING OF MAPS

The last but in no way the least important aspect of cartography is cataloguing, storing and marketing of maps. The construction and publication of maps is a costly affair. Individuals cannot afford to have many of them. It is only the libraries which can collect a large number of maps. But unless these large numbers are properly classified and stored, they may not be of much use to the public. Some of the relevant aspects of these two processes are, therefore, discussed here. This chapter also deals with the problems of marketing the maps.

CATALOGUING

Maps are more diversified in nature than books. Cataloguing and classification of maps are therefore different from those of books. We have already seen how we can classify maps on the basis of scale, subject matter, use and so on. So long as the number of maps is limited, it is easy to locate them for one can easily remember the maps one possesses. But as the number increases, the map librarian is unable to remember each map individually. He needs to classify them so that he can easily lay his hand on the shelf where a particular map is kept by looking into the map catalogue.

Catalogues should incorporate following details: (1) Person or organisation responsible for it (2) cartographer (3) publisher (4) copyright holder (5) title (6) scale (7) edition (8) size (9) place and date of publication.

"It is argued that in the cataloguing of a modern map the author or person responsible for its existence is of least importance, and that the order of the information should be (1) place delineated, (2) subject, that is what the map is intended to show, as canals, railways, physical features, coal fields,

industrial location, etc., (3) date and (4) author. In the cataloguing of an old map the author or cartographer is important, but even so more enquirers ask for a map of a particular area at a certain date than one by a particular cartographer."

"Working on this principle of the place being of the first importance, The British Museum makes its main entry under place, and provides only supplementary entries under the names of cartographers, surveyors and engravers. The Library of congress follows the same method giving only cross references under the names of cartographers, etc." (D.M. Norris.)

The question then arises as to which is the best method of classifying maps. For an answer to this we have to see whether the system used for classification of books can also be applicable to maps. In the classification of books there are two prevalent systems: (1) decimal, and (2) colon. In both the systems books are classified according to the subject they pertain to. So that geography books are numbered from 910 to 913 in the decimal system and under U in the colon system. For sub-fields some more numbers or letters are added. None of these systems take into account the complex problem of classifying maps. Small libraries classifiy maps under geography, and this classification serves the purpose because, at least in India, the number of maps the libraries possess is extremely meagre. Even the National Library at Calcutta has only 21,000 maps. This compares very unfavourably with Library of Congress collection of 3,208,892 maps.

But we know that people in India are becoming map minded and that libraries in universities and other institutions will have to increase their map collection to cater to the needs of the people. That being the case, it is desirable to follow a rational system of classification. It certainly is not the purpose of this chapter to give a blue print in this regard. It is only intended to suggest a method which might suit the Indian conditions.

The first classification should be based on the size and use of maps.

1. Atlases
2. Wall maps
3. Topographical sheets
4. Weather, aeronautical and navigational charts
5. Other maps.

Each of these should be further subdivided on the basis of areas or sub-topics. For example the atlases should be divided into:

1. General (World)
2. Regional.
3. Thematic (economic, social etc.)

Similarly the wall maps and topographical sheets should also be subdivided. In case of the latter, however, the scale will also have to be taken into account. For example, the Survey of India sheets are on the scales of $1'' = 1$ mile, 2 miles, 4 miles, and 6 miles (1:1000,000). It will be desirable to keep these sheets separately scalewise. For each country there should be 4 or 5 shelves set vertically so that this separation is done systematically.

As the libraries in India will have more of the Indian toposheets, and they will also be in great demand, it will be desirable not only to classify them scalewise but also according to numbers the sheets bear.

Among the 'other maps' are a large variety of specialized maps. Some of these are multi-purpose maps but a great majority of them are thematic. It would be desirable to classify the thematic maps on the basis of their information content. There should be physical, economic, political, cultural and other classes and each of them must have the sub-classes. For example, the economic maps may have sub-classes like landuse, crop distribution, mineral resources, industrial, transport, trade etc. as sub-classes.

STORING THE MAPS

Classification is only a part of the problem of map collection. Before acquiring maps from various sources, the librarian must give thought to storage. Storing maps is surely more difficult than storing books. As the size of maps vary from $2'' \times 2''$ (slide) to $10' \times 10'$, special arrangements have to be made for the storage of various sizes. It must also be kept in view that except for atlases, all other maps come in loose sheets. Some of these, like the ones we use as wall maps, are cloth mounted but a vast majority of them are unmounted sheets. The paper on which they are printed usually of good quality, yet within no time it becomes brittle. Moreover, the map users cannot handle large sheets as carefully as they handle books. As a result, the life of maps becomes very short if proper care is not taken from the very beginning. We know how costly maps are, but we also know that their number is too large. It may not therefore be possible to cloth mount all maps, but those which are very costly and also those which are used too very often, must be cloth mounted.

Map mounting is a very simple operation, but if one is not aware of the process well, one is liable to spoil the map. For the guidance of those interested in it, the following procedure is suggested. Have a suitable size of table with regular and clean surface. Wax the surface with a good grade of paste wax. Lay mounting cloth or muslin (a very coarsely woven fabric) on this table, stretch it tight, and thumb pin on the sides. Soak the muslin with

clean water and allow it to dry. Prepare flour paste. Lay the sheet to be mounted on the muslin and wet the map side surface of the sheet with water. Then turn the map over and apply a thin and even layer of paste on its back. Apply the paste on the muslin also. Now turn the sheet mapside up on the muslin. Smoothen it with a tamping brush. If the map consists of more then one sheet, line up adjacent sheets before using tamping brush. Remove the excess paste between the sheet and the muslin with a rolling pin or squeegee. Work from the centre out to the sheet edges. Care must be taken to ensure that the sheet is not wrinkled while removing the excess paste. A damaged sheet cannot be repaired satisfactorily. Allow the sheet to dry for a day and then trim it with a trimming machine. If the map is to be fixed on a roller, do not trim the map on the top and the bottom. Once the map is mounted on cloth, fixing up of the roller is an easy job. A wall map can be used as an example to fix the rollers.

In countries like U.S.A., one can avoid all this procedure by using muslin impregnated with a paroffin type of stiffener called chartex. All that is needed is to put the map sheet on this muslin and press the map with warm iron. This is called dry map mounting.

After the maps are mounted, they have to be put on racks or in cabinets. The type of racks or cabinets which can be used for storing maps will depend upon the size of the maps. If possible such racks should be fitted with wheels so that they can be moved from place to place without noise or difficulty. For topographical sheets, which come in large numbers, we need filing cabinets as shown in Figure 231. In the centre of the face of each drawer can be written the details of the map or map numbers. For keeping original drawings or similar cartographic materials we need draw-index cabinets.

MARKETING THE MAPS

From the cartographic point of view the marketing of maps has much to do with the types of maps which are produced in a country. Maps being the vehicles of conveying certain information, they must cater to the felt needs of the people. It means that the type and quality of maps published will largely depend upon the inter-communication between the map maker and the map users.

Although it is true that the finished maps are the results of the mutual interests of map makers and map users more often than not the two do not see eye to eye. There are several reasons for this, a few of which are given below :

Figure 231 : A cabinet for filing topographic sheets

1. A map maker wants to give information in as clear and aesthetic way as possible. The map user also wants to get information clearly and aesthetically but he wants everything he needs in one map. This is a cartographic impossibility;
2. A map maker's mind works toward the attainment of excellence irrespective of the cost, but a map user want everything cheaply;
3. Even a simple but well designed map takes a lot of time to construct, but from a map users point of view, a line is just a line. He does not realize the effort that goes in compilation and analysis of the data and the thought one has to give to design a well balanced map.

As a result of the above conflicts a map maker is rarely able to satisfy the needs of the people. It is, however, one of the reasons why cartography continues to be a dynamic science.

Cartographer can satisfy the requirements of the map users only if there is a continuing dialogue between the two. The map user must understand the limitations of the cartographer and the latter must know the needs of the former. Cartographer should try to meet the needs of the map user. To do this he must be able to know what these needs are. This can be done by a variety of agencies but the most important among them is the salesman. The job of a salesman is not only to tell the people about the availability of certain maps but also about how a given map can satisfy the felt needs of the customers. But his job does not end here. At times the felt needs of the customers remain unexpressed because they do not ask for maps which do not exist. A customer may like to see a map of the moon, but he may not demand it because he knows that such a map does not exist. It is also the job of a salesman to create awareness about new cartographic products and to inform the publishers and cartographers the nature of maps the users want. Each new awareness creates new demands and each new demand creates new cartographic products. This is how cartographer serves the people.

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